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HURRICANE SURVEY

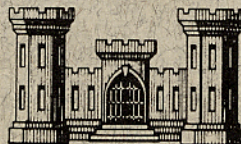


INTERIM REPORT

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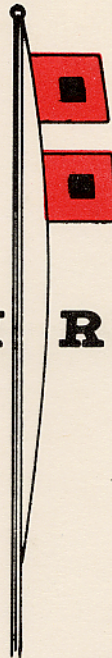
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New England Division - Boston, Mass.

8 FEBRUARY 1957

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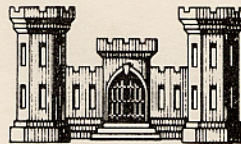
HURRICANE SURVEY



INTERIM REPORT

NEW BEDFORD - FAIRHAVEN

MASSACHUSETTS



Corps of Engineers, U.S. Army - Office of the Division Engineer

New England Division - Boston, Mass.

8 FEBRUARY 1957

TABLE OF CONTENTS

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
	GLOSSARY	xvi
	SYLLABUS	
1	AUTHORITY	1
	SCOPE OF SURVEY	
2	Hurricane Survey	2
3	Navigation Studies	3
4	Coordination	3
	PRIOR REPORTS	
5	Hurricane Reports	3
6	Navigation Reports	4
	DESCRIPTION	
7	Location and Extent of Area	4
8	Harbor Area	5
9	Acushnet River	5
10	Tides	5
11	Geology and Topography	5
12	Area Maps	6
	ECONOMIC DEVELOPMENT	
13	Population	7
14	Industry	7
15	Fisheries	8
16	Power	8
17	Agriculture	8
18	Navigation	8
19	Transportation	9
20	Recreation	9
21	Pollution	10
22	Fish and Wildlife	10

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
CLIMATOLOGY		
23	Climate	11
24	Temperature	11
25	Precipitation	11
26	Runoff and Streamflow Data	12
HISTORY OF HURRICANES		
27	Historical Hurricanes	12
28	Recent Hurricanes	12
29	Hurricane Frequency	13
HURRICANE CHARACTERISTICS		
30	General Description	15
31	Origins and Tracks	15
32	Winds and Barometric Pressure	15
33	Rainfall	16
34	Waves	16
35	Tidal Surges	17
DESIGN HURRICANE TIDAL FLOOD ✓		
36	Wind Field and Barometric Pressure	18
37	Astronomical Tide and Tidal Flooding	18
38	Storm Tracks	20
39	Selection of Design Hurricane	20
40	Design Flood Levels	21
41	Design Waves and Runup	21
42	Design Rainfall	22
43	Design Runoff	22
44	EXTENT AND CHARACTER OF FLOODED AREA	23

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
HURRICANE TIDAL-FLOOD DAMAGES		
45	Flood Damage Survey	24
46	Experienced Tidal-flood Damages	24
47	Recurring Tidal-flood Damages	25
48	Average Annual Tidal-flood Losses	26
49	Scare Costs	26
EXISTING CORPS OF ENGINEERS' PROJECT		
50	Hurricane Protection Project	27
51	Navigation Projects	27
HURRICANE PROTECTION IMPROVEMENTS BY OTHERS		
52	Federal and State Improvements	27
53	Local Improvements	27
IMPROVEMENTS DESIRED		
54	Proposal by Local Interests	28
55	Meetings with Local Interests	28
56	Public Hearing	29
HURRICANE FLOOD PROBLEM AND SOLUTIONS CONSIDERED		
57	Hurricane Flood Damages	30
58	Hurricane Flood Problem	30
59	Degree of Protection Required	31
60	Protective Measures Considered	31
61	Plans Considered	32
	a. Plan "A"	32
	b. Plan "B"	33
	c. Plan "C"	33
	d. Plan "D"	33
	e. Plan "E"	33
	f. Plan "F"	33
	g. Outer Harbor Barrier	34
	h. Waterfront Dikes	34

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
62	Selection of Plan of Protection	34
63	HURRICANE FLOOD CONTROL PLAN	36
64	General Description	36
65	Main Harbor Barrier	36
	a. Barrier	36
	b. Dike Extension	37
	c. Navigation Gates	37
	(1) Operation of the gates	37
	(2) Current velocities	37
	d. Conduit Structure	38
	e. Temporary Bypass Channel	38
66	Clark Cove Dike	38
67	Fairhaven Dike	38
68	Sewer Modifications	39
69	Drainage Modifications	39
70	Lands and Rights-of-way	39
71	Hydrologic and Hydraulic Considerations	40
72	Ponding and Pool Buildup	40
	a. Main Harbor Barrier	41
	b. Clark Cove Dike	41
	c. Fairhaven Dike	41
73	Degree of Protection	42
74	Effect of Plan on Harbor Interests	43
	a. Navigation	43
	b. Pollution	43
	c. Fish and Wildlife	43
	d. Recreation	43
	e. Industry	44
74A	Effect of Plan on Adjacent Shoreline	44
rev. 75	ESTIMATES OF FIRST COSTS AND ANNUAL CHARGES	45
	ESTIMATES OF BENEFITS	
76	Tangible Benefits	47
77	Unevaluated Tangible Benefits	48
78	Intangible Benefits	48

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
79	ECONOMIC JUSTIFICATION	49
80	PROPOSED LOCAL COOPERATION	49
81	APPORTIONMENT OF COSTS AMONG INTERESTS	50
82	COORDINATION WITH OTHER AGENCIES	51
	DISCUSSION	
83	The Problem	52
84	Alternative Solutions	52
85	Selection of Plan	53
86	Effects on Other Interests	53
87	Costs	53
88	Benefits	53
89	CONCLUSIONS	54
90	RECOMMENDATIONS	54

TABLES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Population Statistics	7
2	Recorded Hurricane Occurrences	13
3	Hurricane Tidal-flood Data	19
4	Experienced Tidal-flood Damages	24
5	Recurring Tidal-flood Damages	25
6	First Costs and Annual Charges, Hurricane Protection Plan "F"	46

PLATES

<u>Number</u>	<u>Title</u>
1	General Plan
2	Protection Plan "F"

PHOTOGRAPHS

Following Page

Fishing vessels grounded on Crow Island. Hurricane "Carol, " August 1954	17
Fishing boats and debris, washed ashore Fairhaven. Hurricane "Carol, " August 1954.	17
Marine Park, Popes Island, New Bedford. Hurri- canes of September 1944 and August 1954. ("Carol").	17
"Scare Cost" operations, Acushnet Process Company, New Bedford.	26
Industrial damage inside Acushnet Process Company. Hurricane "Carol, " August 1954.	26
Inundated parking area at Aerovox Corporation, New Bedford, Hurricane "Carol, " August 1954.	26
Tidal-flooding in yard of Revere Copper and Brass, Inc., New Bedford. Hurricane "Carol, " August 1954.	48
Tidal-flooding at State Pier, New Bedford, and residential damage along East Rodney French Boulevard, New Bedford. Hurricane "Carol, " August 1954.	48
Typical damage along East Rodney French Boulevard, New Bedford. Hurricane "Carol, " August 1954.	48

APPENDICES

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
<u>APPENDIX A - GEOLOGY</u>		
A-1	PHYSIOGRAPHY	A-1
A-2	SUBSURFACE INVESTIGATIONS	A-1
	FOUNDATION CONDITIONS IN THE HARBOR	
A-3	Overburden	A-2
A-4	Rock	A-2
A-5	FOUNDATION CONDITIONS FOR LAND DIKES	A-3
	AVAILABILITY OF CONSTRUCTION MATERIALS	
A-6	Dredged Material	A-3
A-7	Pervious Borrow	A-4
A-8	Impervious Borrow	A-4
A-9	Rock Borrow	A-4
A-10	Concrete Aggregates	A-4
A-11	CONCLUSIONS AND RECOM- MENDATIONS	A-5
<u>APPENDIX B - HYDROLOGY AND HYDRAULICS</u>		
B-1	INTRODUCTION	B-1

APPENDIX B (Cont'd)

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
HYDROLOGY		
B-2	Temperature	B-1
B-3	Precipitation	B-2
B-4	Runoff and Streamflow	B-2
B-5	Drainage Areas	B-3
B-6	Hurricane Rainfall	B-4
B-7	Hurricane Winds	B-4
B-8	Hurricane Barometric Pressures	B-6
B-9	Hurricane Tidal-flood Levels	B-8
B-10	Pool Buildup	B-8
HYDRAULICS		
B-11	Design Storm-tide Derivation	B-13
B-12	Wave Heights and Runup	B-13
B-13	Overtopping	B-16
B-14	Current Velocities in Navigation Channel	B-17
B-15	Gated Conduit Size	B-19

APPENDIX C - HISTORY OF HURRICANE OCCURRENCES

C-1	GENERAL	C-1
C-2	SUMMARY OF HURRICANE OCCURRENCES	C-2
C-3	DESCRIPTION	C-10
C-4	HURRICANE TRACKS	C-24

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
------------------	--------------	-------------

APPENDIX D - FLOOD LOSSES AND BENEFITS

GENERAL

D-1	Damage Surveys	D-1
D-2	Loss Classification	D-1

HURRICANE TIDAL-FLOOD DAMAGES

D-3	Tidal-flood Losses	D-2
D-4	Type and Distribution of Losses	D-3
D-5	Recurring Losses	D-5

ANNUAL LOSSES AND BENEFITS

D-6	General	D-7
D-7	Average Annual Tidal-flood Damages	D-8
D-8	Annual Damage-prevention Benefits	D-9
D-9	Fifty-year Damage-prevention Benefits	D-9
D-10	Scare Cost Benefits	D-9
D-11	Enhancement Benefits	D-10
D-12	Summary of Benefits	D-10

APPENDIX E - DESIGN AND COST ESTIMATES

E-1	INTRODUCTION	E-1
E-2	SURVEYS AND EXPLORATIONS	E-1
E-3	DESIGN CRITERIA	E-1

SELECTED PLAN OF PROTECTION (PLAN "F")

E-4	Description of Plan	E-1
	a. General	E-1
	b. Barrier	E-2
	c. Dikes and Walls	E-2
	d. Pertinent Data	E-3

APPENDIX E (Cont'd)

<u>Paragraph</u>	<u>Title</u>	<u>Page</u>
E-5	Modification to Sewerage and Drainage Facilities	
	a. Modifications to Sewer Lines	E-5
	b. Modification to Drainage Lines	E-5
E-6	LANDS AND DAMAGES	E-5
E-7	Relocations	E-6
E-8	Geology of Site	E-6
E-9	Available Materials	E-6
E-10	Plan of Construction	E-7
BASES OF ESTIMATES OF FIRST COST AND ANNUAL CHARGES		
E-11	Cost Estimates	E-7
E-12	Unit Prices	E-7
E-13	Contingencies, Engineering and Overhead	E-8
E-14	Annual Charges	E-8
FIRST COSTS AND ANNUAL CHARGES		
E-15	First Costs	E-8
E-16	Annual Charges	E-8

APPENDIX F - LETTERS OF COMMENT

<u>Subject</u>	<u>Letter</u>
POLLUTION	
1. U. S. Public Health Service	5 Oct. 1956
2. Massachusetts Department of Public Health	6 Sept. 1956
FISH AND WILDLIFE	
U. S. Fish and Wildlife Service	1 Oct. 1956
LOCAL COOPERATION	
1. Governor, Commonwealth of Massachusetts	11 Apr. 1957
2. Mayor, New Bedford, Massachusetts	19 Feb. 1957
3. Chairman, Board of Selectmen, Fairhaven, Massachusetts	6 Feb. 1957

APPENDICES - TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
B-1	Mean Monthly Temperatures (1888-1955)	B-1
B-2	Monthly Precipitation (1814-1955)	B-2
B-3	Streamflow Data	B-3
B-4	Hurricane Rainfalls	B-5
B-5	Hurricane Winds	B-7
B-6	Minimum Barometric Pressures	B-9
B-7	Pool Buildup with Design Runoff	B-10
B-8	Pool Buildup from Runoff in Past Hurricanes	B-12
B-9	Wave Heights and Runup, Hurricane Protection Plan "F"	B-14
B-10	Overtopping of Protective Works, Design Hurricane, Hurricane Protection Plan "F"	
C-1	Historical Hurricanes	C-3
D-1	Experienced Tidal-flood Losses, Hurricane "Carol" 31 August 1954	D-3
D-2	Experienced Tidal-flood Losses, Hurricane "Carol" 31 August 1954	D-4
D-3	Recurring Hurricane Tidal-flood Losses	D-8
E-1	Pertinent Data, Hurricane Protection Plan "F"	E-3
E-2	Estimated First Costs	E-9
E-3	Estimated Annual Charges	E-13

APPENDICES - PLATES

<u>No.</u>	<u>Title</u>
A-1	Geology, Sheet 1 of 4
A-2	Geology, Sheet 2 of 4
A-3	Geology, Sheet 3 of 4
A-4	Geology, Sheet 4 of 4
B-1	Discharge Hydrographs Storm of 17-20 August 1955
B-2	Drainage Areas Contributing Runoff to New Bedford Harbor
B-3	Mass Curves of Rainfall, Storm of 17-20 August 1955
B-4	Mass Curves of Rainfall for Major Storms in New England
B-5	Hurricane Flood Levels, New Bedford Harbor
B-6	Area and Capacity Curves, New Bedford Harbor, Plan "F"
B-7	Tide Curves, Hurricanes of 1938, 1944, 1954
B-8	Plan "F" Navigation Opening Velocities With Maximum Spring Tide
B-9	Plan "F" Navigation Opening Velocities, with Hurricane of 21 September 1938
C-1	Tracks of Selected Hurricanes
D-1	Flood Area and Damages
D-2	Stage-damage Curve

APPENDICES - PLATES (Cont'd)

<u>No.</u>	<u>Title</u>
D-3	Elevation-frequency Curve, Damaging Hurricanes 1815-1955
D-4	Damage-frequency, Protected Area - Plan "F"
E-1	Protection Plan "F," General Plan
E-2	Harbor Barrier and Dike: Plan and Sections
E-3	Harbor Barrier and Dike: Profile and Details
E-4	Harbor Barrier and Dike: Sector Gate
E-5	Clark Cove Dike: Plan, Profile and Sections
E-6	Fairhaven Dike: Plan, Profile and Section

GLOSSARY

- HURRICANE SURGE:** the mass of water causing an increase in the elevation of the water surface above predicted astronomical tide at the time of a hurricane; it includes wind set-up; sometimes the maximum increase in elevation is referred to as the surge.
- HURRICANE TIDE:** the rise and fall of the water surface during a hurricane, exclusive of wave action.
- KNOT:** a velocity equal to one nautical mile (6080.2 ft.) per hour (about 1.15 statute miles per hour).
- OVERTOPPING:** that portion of the wave runup which goes over the top of a protective structure.
- PONDING:** the storage of water behind a dike or wall from local runoff and/or overtopping by waves.
- POOL BUILDUP:** the increase in elevation of water surface behind a structure due to runoff and/or overtopping by waves.
- RUNUP:** the rush of water up the face of a structure on the breaking of a wave. The height of runup is measured from the still water level.
- SIGNIFICANT WAVE:** a statistical term denoting waves with the average height and period of the one-third highest waves of a given wave train.
- SPRING TIDE:** a tide that occurs at or near the time of new and full moon and which rises highest and falls lowest from the mean level.
- STILL WATER LEVEL:** the elevation of the water surface if all wave action were to cease.
- STORM SURGE:** same as "hurricane surge."

GLOSSARY (Cont'd)

WAVE HEIGHT: the vertical distance between the crest and the preceding trough.

WAVE TRAIN: a series of waves from the same direction.

WIND SET-UP: the vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water.

SYLLABUS

The Division Engineer finds that a serious problem of hurricane tidal flooding exists in the highly industrialized and heavily populated area adjacent to New Bedford - Fairhaven Harbor, Massachusetts. The acuteness of the problem is indicated by the fact that three severe hurricanes have struck the area in the past 20 years and, upon their recurrence, would cause total flood damages of about \$62,000,000, at 1956 prices. Average annual damages from tidal flooding amount to nearly \$960,000.

The Division Engineer recommends, for the protection of the City of New Bedford and the Towns of Fairhaven and Acushnet, Massachusetts, the construction of a rock-faced, earth-filled barrier across New Bedford - Fairhaven Harbor, a dike extension along the New Bedford shore, supplemental dikes and walls in the Clark Cove area of New Bedford and in Fairhaven, and other appurtenant structures. The estimated first cost is \$17,200,000 including \$15,490,000 to the United States and \$1,710,000 to local interests.

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
150 CAUSEWAY STREET
BOSTON 14, MASS.

8 February 1957

SUBJECT: Interim Report on Hurricane Survey, New Bedford,
Fairhaven and Acushnet, Massachusetts

TO: Chief of Engineers
Department of the Army
Washington 25, D. C.
ATTENTION: ENGWF

AUTHORITY

1. This report is submitted in compliance with the following authorizations:

a. Public Law 71, Eighty-fourth Congress, First Session, approved 15 June 1955, which reads as follows:

"Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That in view of the severe damage to the coastal and tidal areas of the eastern and southern United States from the occurrence of hurricanes, particularly the hurricanes of August 31, 1954, and September 11, 1954, in the New England, New York, and New Jersey coastal and tidal areas, and the hurricane of October 15, 1954, in the coastal and tidal areas extending south to South Carolina, and in view of the damages caused by other hurricanes in the past, the Secretary of the Army, in cooperation with the Secretary of Commerce and other Federal agencies concerned with hurricanes, is hereby

authorized and directed to cause an examination and survey to be made of the eastern and southern seaboard of the United States with respect to hurricanes, with particular reference to areas where severe damages have occurred.

"Sec. 2. Such survey, to be made under the direction of the Chief of Engineers, shall include the securing of data on the behavior and frequency of hurricanes, and the determination of methods of forecasting their paths and improving warning services, and of possible means of preventing loss of human lives and damages to property, with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams, and other structures, warning services, or other measures which might be required."

b. A resolution of the Committee on Public Works of the United States Senate, adopted 9 November 1954, which reads:

"RESOLVED...., That the Board of Engineers for Rivers and Harbors, created under Section 3 of the River and Harbor Act, approved June 13, 1952, be, and is hereby, requested to review the reports of the Chief of Engineers on New Bedford Harbor, Massachusetts, printed in House Document 348, Seventy-first Congress, Second Session, and other reports, with a view to determining whether the existing project should be modified in any way at the present time in view of the recent hurricane damage in the area."

The Chief of Engineers, by letter dated 21 February 1956, directed that studies in connection with the above authorizations be combined since both are concerned with hurricane damages in the New Bedford area.

SCOPE OF SURVEY

2. HURRICANE SURVEY

This interim report of survey scope comprises the result of an examination and survey of hurricane tidal flooding in the towns of New Bedford, Fairhaven, and Acushnet, exclusive of the Sconticut

severe storm, struck at a time of low tide and flooding was consequently less severe. Further data on the history of hurricanes are contained in Appendix C.

29. HURRICANE FREQUENCY

The distribution of recorded hurricane occurrences in the New Bedford area, by estimated degrees of intensity, is shown in Table 2 below:

TABLE 2

RECORDED HURRICANE OCCURRENCES

New Bedford-Fairhaven Harbor Area, Massachusetts

<u>Category</u>	<u>Years</u>				<u>Total</u>
	<u>1635-1700</u>	<u>1701-1800</u>	<u>1801-1900</u>	<u>1901-1955</u>	
A: Causing tidal flooding	2	2	5	3	12
B: Damage from wind or rainfall	No record	1	5	7	13
C: Threat to area; no damage	No record	3	6	26	35
Total	2	6	16	36	60

The fact that there are records of 36 hurricane occurrences in the first 55 years of the 20th century (1901-1955), as compared with 24 occurrences in the 266-year period between 1635 and 1900, may be attributable to the lack of records on early storms and should not be accepted as conclusive indication of any trend toward greater frequency of occurrences in recent times.

As indicated by recorded facts, the New Bedford-Fairhaven area has experienced hurricane tidal flooding upon at least eight

Fairhaven areas. Part II, Chapter XXXIX, of the unpublished report of the New England-New York Inter-Agency Committee on "The Resources of the New England-New York Region", prepared pursuant to a Presidential directive of October 9, 1950, contains a section devoted to hurricanes in the northeastern United States. This section presents a brief history of hurricanes in New England, an inventory of experienced losses in recent hurricanes, and a discussion of several methods of reducing damages. Specific measures to prevent severe damage at several localities along the New England coast, including New Bedford, are briefly discussed.

6. NAVIGATION REPORTS

The New Bedford-Fairhaven Harbor has been the subject of many navigation reports since 1853. A favorable report of survey scope, House Document No. 348, submitted in 1930, formed the basis for authorization of the present 30-foot entrance channel. Two subsequent favorable reports, recommending maneuvering areas, anchorages, and branch channels, were submitted in 1934 and 1937 respectively, and are published in River and Harbor Committee Documents Nos. 16, Seventy-fourth Congress, and 25, Seventy-fifth Congress.

DESCRIPTION

7. LOCATION AND EXTENT OF AREA

The city of New Bedford and the town of Fairhaven, Massachusetts, are located in Bristol County, about 50 miles south of Boston, Massachusetts, and about 30 miles southeast of Providence, Rhode Island. They are situated on the west shore of Buzzards Bay which opens to the Atlantic Ocean. The town of Acushnet adjoins Fairhaven on the north.

The combined area of New Bedford, Fairhaven and Acushnet covers approximately 51 square miles of which about 20 square miles are in New Bedford, 12 in Fairhaven, and 19 in Acushnet. The three communities have a total water frontage of about 37 miles, about 18 miles of which are in the area of this report. The remaining 19 miles constitute the shore line in the Sconticut Neck and West Island area of Fairhaven. Of the 18 miles in the area of this report, about ten are in New Bedford, six in Fairhaven and two in Acushnet.

8. HARBOR AREA

The New Bedford-Fairhaven Harbor, which separates New Bedford on the west from Fairhaven on the east, is the estuary of the Acushnet River. The harbor area comprises a broad outer bay, about three miles long and two miles wide, between Clark Point on the west and Sconticut Neck on the east; an inner harbor, about $1\frac{1}{2}$ miles long and $\frac{3}{4}$ mile wide, extending north to the crossing of U. S. Route No. 6 at Fish and Popes Islands; and the lower $1\frac{1}{4}$ miles of the Acushnet River, below the head of navigation at the Coggeshall Street Bridge. The approach to the harbor from deep water in Buzzards Bay is through an improved entrance channel with a project depth of 30 feet at mean low water. The outer harbor is exposed to easterly and southerly storms. The inner harbor and the Acushnet River are well protected except against severe southerly blows. Both the inner and outer harbor areas are particularly vulnerable to the high waves and tidal surges created by hurricanes approaching from the south.

9. ACUSHNET RIVER

The Acushnet River has its source in New Bedford Reservoir in the north area of Acushnet, Massachusetts. From its origin the river flows generally south about four miles to tidewater at Saw Hill Dam, and then continues south for about three miles to the New Bedford-Fairhaven Bridge at the head of the harbor. The river drains an area of 18.4 square miles above the head of tidewater. The watershed is relatively low and flat and contains large areas of swampland which tend to retard the runoff.

10. TIDES

The mean range of tide in the New Bedford-Fairhaven Harbor is 3.7 feet. Spring tides have an average range of 4.6 feet and a maximum range of about 5.8 feet. A maximum spring tide will reach an elevation 5.0 feet above mean low water (3.2 feet above mean high water). The time interval for a complete tidal cycle averages about 12 hours and 25 minutes. This results in the daily occurrence of two low and two high waters on an average of six out of every seven days. Hurricane tides are discussed in paragraphs 37 and 40 of this report.

11. GEOLOGY AND TOPOGRAPHY

The geology of the area is that of a single rock formation, the Dedham Granodiorite of tentative Devonian Age. This formation,

which is believed to have been intruded into older metamorphic and volcanic rocks, consists of a wide variety of comingled igneous rock types. Bedrock in the area is concealed largely under glacial overburden which has tended to neutralize the relief. Land areas adjacent to the harbor possess poor drainage as a result of the damming of pre-glacial drainage channels by glacial debris. See Appendix A for further data on the geology of the area.

The topography of New Bedford, Fairhaven and Acushnet is one of moderately low relief with elevations ranging from sea level along the coast to a maximum of 183 feet above sea level in west central New Bedford. The south part of New Bedford and a major portion of Fairhaven lie below an elevation of 50 feet msl. The shore line is one of youthful submergence characterized by bayhead beaches, tombolos, and low rocky headlands.

12. AREA MAPS

New Bedford, Fairhaven and Acushnet, and the watershed of the Acushnet River, are shown on standard quadrangle sheets of the U. S. Geological Survey at a scale of 1:31,680, and on quadrangles of the U. S. Army Map Service at a scale of 1:25,000. The harbor area and its approaches are shown on U. S. Coast and Geodetic Survey Charts Nos. 249, 252, and 1210. A map of the area is included as Plate 1 of this report.

ECONOMIC DEVELOPMENT

13. POPULATION

In 1950, New Bedford was the 6th largest city in the Commonwealth of Massachusetts and the 96th in size in the United States. The adjoining towns of Acushnet and Fairhaven, which are considerably smaller in population, are principally residential in character. The total population of New Bedford, Fairhaven, and Acushnet, according to the state census of 1955, is approximately 124,000. About 85 percent of this total population is located in New Bedford. Population statistics for the three localities in the survey area are given in Table I below.

TABLE I

POPULATION STATISTICS

New Bedford, Fairhaven, and Acushnet, Massachusetts

<u>Year</u>	<u>New Bedford</u>	<u>Fairhaven</u>	<u>Acushnet</u>	<u>Total</u>
1920	121,217	7,291	3,075	131,583
1940	110,341	10,938	4,145	125,424
1950	109,189	12,764	4,401	126,354
1955	105,488	13,376	4,892	123,756
1940	102,000	14,339		

14. INDUSTRY

The survey area is highly industrialized. The employed industrial labor force is about 40,000 of whom 65 percent are engaged in manufacturing as compared with a national average of 25 percent. Ninety-five percent of the total labor force are employed in the city of New Bedford. Of approximately 270 manufacturing plants in the area, 255 are in New Bedford. The most important manufactures are textiles and related items, electrical and electronic equipment, rubber products, copper and brass rolling mill products, and machinery. New Bedford's economy rests heavily on textile manufacturing, with 110 plants employing nearly one-half of the city's industrial labor force. Next in importance, measured by the number of employees, is the manufacture of electrical and electronic items at four New Bedford plants. Among the limited industrial activities of Fairhaven, the operation of boatyards for the repair and outfitting of fishing and pleasure boats is important. The total annual value of all products presently manufactured in the area is estimated at \$250,000,000, of which over 50 percent represents value added by manufacture.

15. FISHERIES

Once the leading whaling port of the United States, New Bedford and Fairhaven Harbor still ranks as one of the leading fishing ports in the country. For the past several years it has alternated between fourth and fifth place as determined by value of catch. It is also the world's leading scallop port. In 1955, the landings of fish and shellfish exceeded 40,000 tons with a total value of nearly \$12,000,000. Scallops accounted for about 17 percent of this total weight and 60 percent of the total value. Approximately 1,200 people are employed in the local fishing industry and allied pursuits dependent on fishing, such as filleting, canning, freezing, and the operation of shipyards.

16. POWER

The area is served by the New Bedford Gas and Edison Light Company with a 137,500 kw steam station on the New Bedford waterfront, about one-half mile south of the New Bedford-Fairhaven Bridge. The plant is located in the area that was inundated by tidal flooding in 1938 and 1954. The water of the harbor is utilized for cooling purposes.

17. AGRICULTURE

Agriculture is relatively limited in the survey area, but poultry raising and dairy farming are important activities, especially in the towns of Acushnet and Fairhaven. Some tree fruit is grown in Acushnet. Farms in the area range in size up to about 150 acres. There is no agriculture of any consequence in the areas inundated by hurricane tides.

18. NAVIGATION

Commerce in New Bedford and Fairhaven Harbor averaged just under 600,000 tons annually for the period 1942-1949. From 1949 to 1954, the annual tonnage ranged from a high of 490,000 in 1950 to a low of 215,000 in 1954. This decrease is attributed mainly to reduced receipts of coal which formerly accounted for 50 to 80 percent of the annual commerce. Approximately 50 percent of the total commerce in 1954 was in petroleum products, and 29 percent in coal and coke. Passenger service dropped from a total of over 222,000 in 1945 to 5,000 in 1952, but has since increased, amounting to nearly 37,000 in 1954. Most of the passenger traffic is to the islands of Martha's Vineyard and Nantucket, located off the south coast of Massachusetts.

Annual vessel traffic during the 5-year period from 1950 to 1954 averaged 10,400 trips, ranging from a total of about 14,900 trips in 1951 to 7,700 trips in 1954. In 1954 only 9 trips were made by vessels with drafts of 26 feet or more, 5 of these being T-2 tankers and 4 colliers. During this same year, 18 trips were made by vessels with drafts ranging from 19 to 25 feet. The remainder of the 1954 traffic, about 7,675 trips, were made by barges, fishing boats, ferries, motor vessels, and Federal craft, all with drafts of 18 feet or less. Unofficial figures for 1955 indicate that there was no significant increase in deep draft commerce during the year.

The fishing fleet operating out of New Bedford and Fairhaven Harbor is of major importance to the economy of the area. The fleet numbers about 200 vessels with drafts ranging from 6 to 14 feet, each of which presently makes about 20 round trips a year.

19. TRANSPORTATION

The area is served by a network of modern highways. The two principal routes are U. S. No. 6 which passes through New Bedford and Fairhaven in an east-west direction, and Massachusetts No. 140 which runs north from New Bedford. A branch line of the New York, New Haven and Hartford Railroad provides passenger and freight service between New Bedford and Boston. Northeast Airlines maintains scheduled flights in and out of the New Bedford airport. Improved waterways provide access to New Bedford and Fairhaven for commercial vessels and pleasure boats. The New Bedford, Woods Hole, Martha's Vineyard and Nantucket Steamship Authority operates regularly scheduled steamer ferry service between New Bedford and Nantucket, Massachusetts.

20. RECREATION

The waters of New Bedford and Fairhaven Harbor and Buzzards Bay provide excellent facilities for bathing, boating, and off-shore fishing which are the principal recreational activities of the area. The many fine beaches in the area all meet the standard set by the Massachusetts Department of Public Health for safe bathing water. The city of New Bedford maintains a public bathing beach on the east shore of Clark Cove. Among several places of historical interest which attract vacationers annually are Fort Phoenix, a Revolutionary War Fort, and the Whaling Museum, containing many relics of the New Bedford whaling fleet.

21. POLLUTION

Although some sewage and industrial wastes are discharged into the Acushnet River, the harbor, and nearby coves, there are no areas where the degree of pollution has adversely affected the bacterial quality of the water for recreational purposes. However, clam flats in New Bedford and Fairhaven Harbor have been closed by state health authorities because of pollution.

There are no sewage treatment plants in New Bedford, Fairhaven, or Acushnet. The sewerage lines in Acushnet and Fairhaven empty directly into the Acushnet River or into the harbor. In New Bedford, an intercepting sewer, with maximum dimensions of 84 by 92 inches, was built in 1912 to collect the dry-weather flow and carry it to a submerged outfall extending 3,300 feet into Buzzards Bay off the southerly end of Clark Point. Seven pumping stations have been constructed to lift the flow from low-lying areas into the main interceptor. The capacity of the interceptor is sufficient to handle the combined flow of sanitary sewage and the runoff from a very light rainfall. During periods of heavy precipitation, such as may be experienced during some hurricanes, the excess flow is diverted through over-flow lines into the river, the harbor, and Clark Cove.

22. FISH AND WILDLIFE

Sports fishing is of little importance in the immediate harbor area. No wildlife habitats of any consequence are located along the waterfront areas of New Bedford, Fairhaven, and Acushnet that are affected by hurricane tides.

CLIMATOLOGY

23. CLIMATE

The New Bedford-Fairhaven area has a temperate and changeable climate marked by four distinct seasons which are characteristic of its latitude and of New England. Owing to the moderating influence of the nearby ocean, and particularly to the variable movements of high- and low-pressure areas associated with continually changing weather patterns, extremes of either hot or cold weather are rarely long lasting. In the winter, coastal storms frequently bring rainfall in contrast to snow in the more northerly areas. In the summer, cooling relief from hot, humid weather is provided by sea breezes from the southwest, thunder storms from the west, and cool air from the north. The prevailing winds are northwesterly in the winter and southwesterly in the summer. High winds, heavy rainfall, and abnormally high tides occur with unpredictable frequency in the hurricane months of August, September, and October.

24. TEMPERATURE

The average annual temperature of the New Bedford-Fairhaven area, based on records for the past 68 years (1888-1955), is about 50°F. Average monthly temperatures vary from 29° in February to 71°F in July. (See Table B-1, Appendix B.) Recorded extremes in temperature range from a minimum of -12° to a maximum of 97°F. Freezing temperatures may be expected from the latter part of November until late in March.

25. PRECIPITATION

The annual precipitation over the New Bedford area during the past 142 years (1814-1955) has ranged from a minimum of 28 inches in 1930 to a maximum of 65 inches in 1829. The average annual rainfall amounts to 45 inches, distributed rather uniformly throughout the year. Average monthly rainfall varies between 3.05 inches for June and 4.18 inches for August. Extremes of monthly precipitation have ranged from 0.01 inch in June 1949 to 18.72 inches in August 1826. Annual snowfall, based on 49 years of record (1889-1947) averages 35 inches. A tabulation of monthly precipitation data is contained in Appendix B.

26. RUNOFF AND STREAMFLOW DATA

Although there are no gaging stations in the watershed of the Acushnet River, runoff data for its drainage area of 18.4 square miles at Saw Mill Dam, at the head of tidewater, has been estimated from the flow records of the U. S. Geological Survey gaging stations on the Wading River. Since the gaged areas in the Wading River Basin are similar in topographic characteristics to the Acushnet River watershed, it has been feasible to estimate runoff for the Acushnet River for design purposes. For further discussion[see paragraphs 42 and 43.

HISTORY OF HURRICANES

27. HISTORICAL HURRICANES

Descriptions of violent storms affecting southern New England, including the New Bedford-Fairhaven area, are found in the earliest records of the Massachusetts Bay Colony. William Bradford, in his chronicle, "Of Plymouth Plantation, 1620-1647," describes a very great hurricane on 15 August 1635. An account of another great storm, on 3 August 1638, is recorded by Governor Winthrop in "The History of New England from 1630 to 1649". Early newspaper and journal accounts contain a number of references to intense storms accompanied by destructive winds during the period from 1638 to 1815. The two most notable storms in this period are those of 30 October 1723 and 24 October 1761.

28. RECENT HURRICANES

More numerous records are available of hurricane occurrences subsequent to the year 1815, with very good records existing for the past 50 years. Among the more famous storms in this past 141-year period, causing tidal flooding of damaging proportions, are the following:

- | | |
|-----------------------|-----------------------------|
| a. 23 September 1815 | e. 10 December 1878 |
| b. 29-30 October 1866 | f. 21 September 1938 |
| c. 8 September 1869 | g. 14 September 1944 |
| d. 23 October 1878 | h. 31 August 1954 ("Carol") |

The 1938 and 1954 hurricanes both struck at a time nearly coincident with a high gravitational tide and caused millions of dollars of damage from tidal flooding. The hurricane of 1944, although a very

severe storm, struck at a time of low tide and flooding was consequently less severe. Further data on the history of hurricanes are contained in Appendix C.

29. HURRICANE FREQUENCY

The distribution of recorded hurricane occurrences in the New Bedford area, by estimated degrees of intensity, is shown in Table 2 below:

TABLE 2

RECORDED HURRICANE OCCURRENCES

New Bedford-Fairhaven Harbor Area, Massachusetts

<u>Category</u>	<u>Years</u>				<u>Total</u>
	<u>1635-1700</u>	<u>1701-1800</u>	<u>1801-1900</u>	<u>1901-1955</u>	
A: Causing tidal flooding	2	2	5	3	12
B: Damage from wind or rainfall	No record	1	5	7	13
C: Threat to area; no damage	No record	3	6	26	35
Total	2	6	16	36	60

The fact that there are records of 36 hurricane occurrences in the first 55 years of the 20th century (1901-1955), as compared with 24 occurrences in the 266-year period between 1635 and 1900, may be attributable to the lack of records on early storms and should not be accepted as conclusive indication of any trend toward greater frequency of occurrences in recent times.

As indicated by recorded facts, the New Bedford-Fairhaven area has experienced hurricane tidal flooding upon at least eight

occasions since 1815. Of these eight experiences, reliable information on high-water marks is available only for the hurricanes of 1938, 1944 and 1954. General descriptions indicate that the flood stages in the five storms of the 19th century were probably below those of 1938 and 1954. The three known high-water marks in recent hurricanes and five estimated flood levels in earlier hurricanes have been used in preparing an elevation-frequency curve. In preparing this curve, account has been taken of the historical hurricanes of 1635 and 1638, their elevations of flooding being assumed higher than experienced in 1938. See Plate D-3, Appendix D.

With respect to seasonal variation of hurricane occurrences in southern New England, the period of greatest activity extends from early August to the end of October. However, records indicate occurrences as early as the middle of June and as late as the middle of December.

HURRICANE CHARACTERISTICS

30. GENERAL DESCRIPTION

The term "hurricane" is applied to an intense cyclonic storm originating in tropical or subtropical latitudes in the Atlantic Ocean north of the Equator. Accumulation of heat close to the surface of the water provides energy for water vaporization and the movement of masses of moist tropical air. A hurricane is characterized by low barometric pressures, high winds (75 miles per hour or greater), heavy clouds, torrential rain, tremendous waves and tidal surges.

31. ORIGINS AND TRACKS

Most of the hurricanes that have affected the eastern coast of North America have formed either near the Cape Verde Islands or in the western Caribbean Sea. Cape Verde hurricanes move westerly for a number of days with a forward speed of about 10 mph. Occasionally, they proceed straight to the coast of Texas, but generally, after reaching the middle Atlantic Ocean, they recurve northerly and then easterly. Frequently they cross the West Indies, sometimes striking the eastern coast of the United States between Key West, Florida, and Cape Cod, Massachusetts. After recurving, the storms usually increase their forward speed to a rate of 25 to 30 mph and occasionally to a speed of 60 mph. The hurricanes which form in the Caribbean Sea generally move in a northerly direction, cross Cuba, then strike either the Gulf or the southeastern shores of the United States. The hurricanes that most severely affect New England usually approach from the south-southwest after recurving east of Florida and skirting the Middle Atlantic states. The paths of a number of selected hurricanes are shown on Plate C-1, Appendix C.

32. WINDS AND BAROMETRIC PRESSURE

The highest winds of a hurricane are those within a circular region extending from the edge of the "eye", or calm center, outward for 10 to 15 miles. The diameter of the eye is usually about 15 miles, although the eye of a mature hurricane is frequently 20 to 30 miles in diameter. Wind movement is not directly toward the low pressure cyclone center or eye of the hurricane but approaches the center in a counter-clockwise spiral. Consequently, the highest wind velocities occur at points to the right of the center of the hurricane where the spiral wind movement and the movement due to the forward motion of the storm are in the same direction. Since destruction by the wind is greatest in the area on the right side of the hurricane, this area is known as the "dangerous semi-circle."

Atmospheric pressure falls rapidly as the center of the hurricane approaches and as the velocity of the wind increases. Minimum barometric readings do not always occur in the center of the eye. In some instances the minimum is reached at the beginning of the calm period while in others the minimum is reached at the end of the calm period. Usually the barometric low is about two inches below the normal sea level pressure of 30 inches. However, in several hurricanes, pressures as low as three inches below normal have been recorded. In the United States the lowest barometric pressure ever recorded was 26.35 inches at the northern end of Long Key, Florida, on 2 September 1935.

33. RAINFALL

Another characteristic of a hurricane is the heavy rainfall that usually accompanies the storm. At the edge of the disturbance rainfall is light, normally in the form of showers. As the center approaches, the showers increase in frequency and intensity, becoming heavy to excessive near the eye. The heaviest rain usually falls ahead of the eye, driving torrentially from spiral bands of clouds that sometimes produce nearly two inches of rain per hour. For a 24-hour period, amounts exceeding 20 inches are not uncommon. Record rainfall near the survey area occurred during Hurricane Diane (August 1955) when a rainfall of 15.7 inches in 24 hours (total storm rainfall of 19.8 inches in 48 hours) was experienced at Westfield, Massachusetts, 100 miles northwest of New Bedford.

34. WAVES

Much of the hurricane damage is caused by waves generated by hurricane winds. Vessels at sea suffer greatly in the northeast quadrant of the hurricane and in the confused seas of the storm center where waves 45 feet or more in height have been reported. These mountainous waves appear in wild, pyramidal masses and the magnitude of their destructive power is revealed only in the appalling record of lives lost and ships sunk at sea or wrecked on shoals and shores. Such giant ocean waves will traverse tremendous distances while diminishing in size and strength, reaching distant shores one or two days in advance of the hurricane and causing damage even before the onset and release of the fury contained in the storm proper.

In the deep water of the open ocean the height, period, and velocity of many of the waves produced are a function of the wind velocity. The ultimate size of the waves depends upon the force and duration of the wind and the fetch or distance the wave

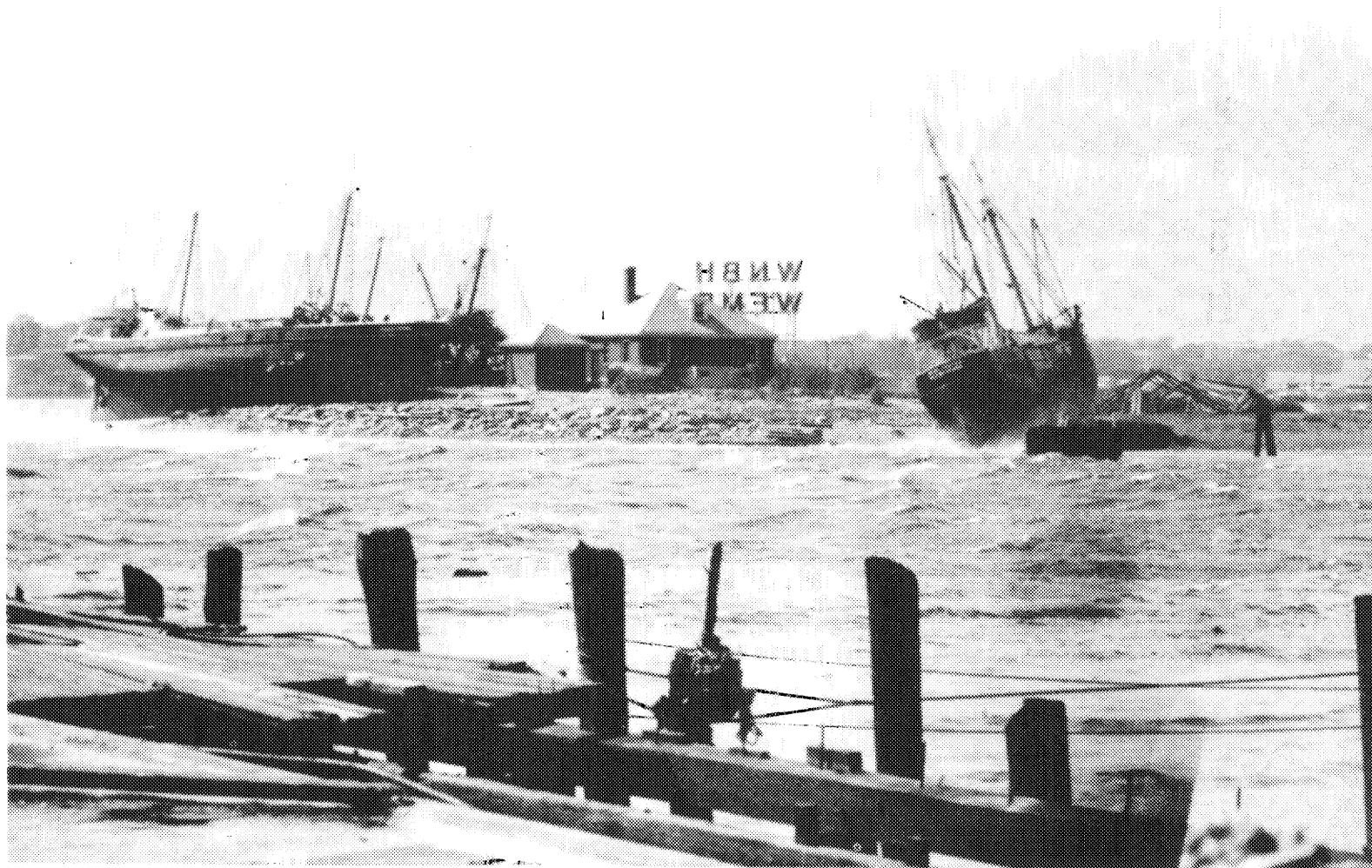
travels. As ocean waves come into shoal waters, their forward movement is slowed by friction on the bottom, and they rise to a new height before they are dissipated in shoal waters or break on the shore. Driven by hurricane winds, the breaking waves will run up on a shelving beach or overtop vertical structures well above the wave heights, so that reports of wave and flood damage from 5 to 25 feet above water level are not uncommon. Hurricane waves do great damage to shorefront land and buildings and to vessels and small craft. In the hurricane of 1938, independent observations indicated a maximum wave height in the New Bedford area of 14 feet at Butler Flats Light, in an exposed location about 1.6 miles southeast of Palmer Island, and heights of four feet in the harbor area north of Palmer Island. Local estimates of wave heights in the harbor during Hurricane "Carol" (August 1954) range from four to seven feet.

35. TIDAL SURGES

Flooding results from the movement of the storm surge, or rise in water level, onto a shoaling coast or into a bay or inlet. The surge is caused by a combination of hurricane winds and low barometric pressure in a storm having a track and speed of forward movement synchronized with the normal pattern of tidal movement and oscillations of the sea in the open ocean.

Usually the rise of the sea is gradual as the center of the storm approaches but sometimes it comes with great swiftness. Rising waters accompanying hurricanes have been called "tidal waves", although they are not tides in the ordinary sense. The history of terrible storms, revealing many instances of cities and towns flooded, with thousands of lives lost, evidence that such rises are not always gradual.

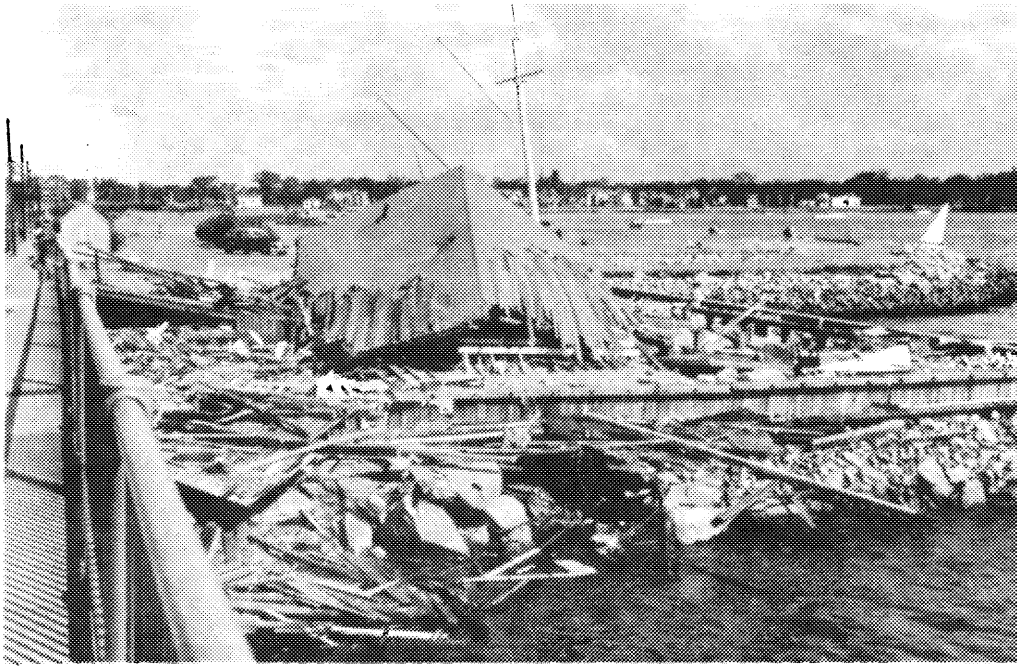
Usually the level of the storm surge is increased by a rising ocean bed and favorable shore contours, factors which similarly affect the astronomical tide in shore locations. The ordinary rise of the tide amounts to only one or two feet in the open ocean while its range is often ten to twelve feet at coastal points. In certain bays and channels the rise is 25 to 50 feet above low water. The times of ebb and flow of such tides are of course well known, but the storm surge comes so rarely to any one community that it is seldom anticipated in its fully developed form. A well defined storm surge is not developed unless the slope of the ocean bed and the contour of the coastline are favorable to its rise, in combination with the proper direction of the storm track and speed of movement.



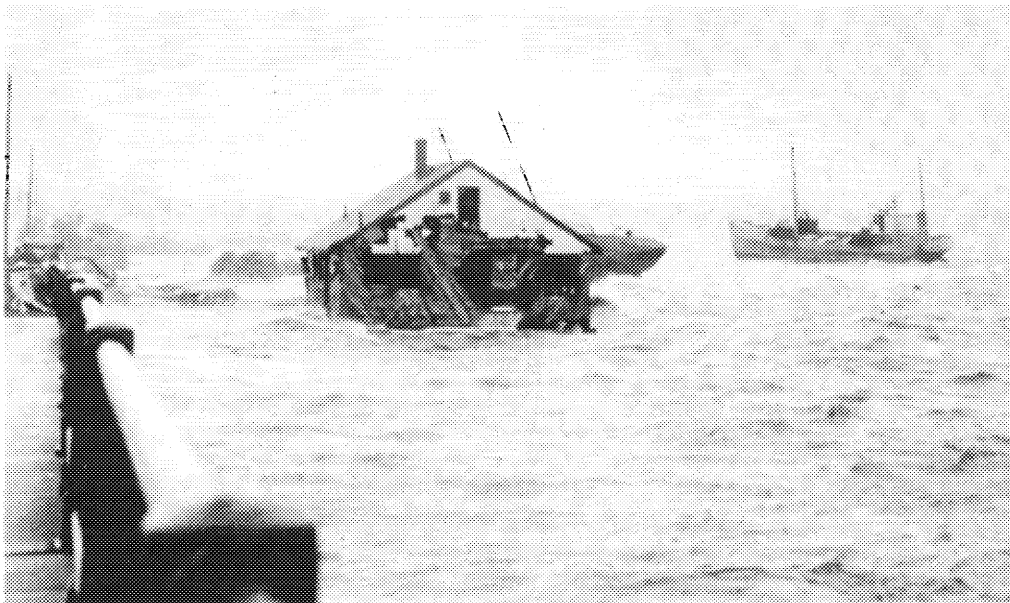
Fishing vessels grounded on Crow Island, New Bedford and Fairhaven Harbor, during Hurricane "Carol," 31 August 1954. (Photo by New Bedford Standard-Times.)



Fishing boats and debris washed ashore at east end of New-Fairhaven Bridge during Hurricane "Carol," 31 August 1954. (Photo by New Bedford Standard-Times.)



Marine Park, Popes Island, after hurricane of 14-15 September 1944, showing wreckage of yacht club. (Photo by Hollywood Studio, New Bedford.)



Marine Park, Popes Island, during Hurricane "Carol," 31 August 1954, showing partially destroyed store, formerly the yacht club, and two stranded fishing vessels. (Photo by Hollywood Studio, New Bedford.)

DESIGN HURRICANE TIDAL FLOOD

36. WIND FIELD AND BAROMETRIC PRESSURE

In New England, the maximum recorded wind velocity in a past hurricane is a gust of 186 mph at the Blue Hill Observatory, Milton, Massachusetts, in September 1938. The sustained 5-minute velocity at this location, about 40 miles north of New Bedford, during this same hurricane, is 121 mph. At Providence, Rhode Island, about 30 miles northwest of New Bedford, the maximum gust and 5-minute velocity in this same hurricane were 95 and 87 mph, respectively. During the hurricane of September 1944, the maximum recorded gust in New England was 104 mph at Chatham, Massachusetts, 45 miles east of New Bedford. Peak gusts measured during Hurricane "Carol," in August 1954, were 142 mph at Mount Washington, New Hampshire, 180 miles north of New Bedford; and 130 mph at Block Island, Rhode Island, 45 miles to the southwest. The maximum velocity of record at New Bedford was registered during the Hurricane of September 1944 and again during Hurricane "Carol," gusts of 85 mph being measured during both of these two hurricanes.

Low atmospheric pressures are characteristic of the "eye" of a hurricane. The lowest barometric pressure ever recorded in New England is 28.04 inches at Hartford, Connecticut, during the 1938 hurricane. The lowest at New Bedford is 28.42 inches in the September 1944 hurricane. The New England low during this latter storm is 28.30 inches at Westerly, Rhode Island. In Hurricane "Carol" the pressure fell to 28.20 inches at Storrs, Connecticut, and 29.05 inches at New Bedford. Further data on wind velocities and barometric pressures in past hurricanes are included in Appendix B.

37. ASTRONOMICAL TIDE AND TIDAL FLOODING

An important factor in determining the height of flooding from a tidal surge is the stage of the normal tide at the time the hurricane surge arrives at the coast. The surge in the September 1938 hurricane added 10 feet to the astronomical tide at New Bedford and caused flooding to an elevation of 12.5 feet msl (approximately 10.7 feet mhw). The hurricane of 31 August 1954 (Hurricane "Carol"), with a 9.9-foot surge caused flooding to an elevation of 11.9 feet msl. Hurricane high-water elevations, predicted coincident astronomical tides, and the storm surges in the three major hurricanes to strike New Bedford Harbor in recent times, are tabulated in Table 3 on the following page.

TABLE 3

HURRICANE TIDAL-FLOOD DATANew Bedford and Fairhaven Harbor, Massachusetts

<u>Hurricane</u>	<u>Time of Peak (EST)</u>	<u>Hurricane High-Water Elevation (feet msl)</u>	<u>Coincident Astronomical Tide (feet msl)</u>	<u>Storm Surge (feet)</u>
21 Sep 1938	5:45 PM	12.5	2.5	10.0
14 Sep 1944	11:10 PM	8.2	-1.3	9.5
31 Aug 1954	10:30 AM	11.9	2.0	9.9

The duration of tidal flooding, above the elevation of mean high water, was six hours in the 1938 hurricane; and eight hours in the hurricanes of September 1944 and August 1954. Further data on tidal high water elevation may be found in Appendix B.

Peak flooding in the 1938 and 1954 hurricanes occurred practically simultaneously with a high tide of spring-tide range; and the peak of the 1944 hurricane occurred near the time of a low tide. The hurricane surges upon all three occasions were nearly equivalent. If these three storms had struck New Bedford at a time coincident with a maximum spring tide of 3.2 feet msl, flooding would have been experienced to an elevation of 13.2 feet msl in 1938, 12.7 feet in 1944, and 13.1 feet msl in 1954; or 0.7, 0.2 and 0.6 foot higher than was actually experienced in 1938.

In determining future tidal flood levels, one factor to be considered is the rise in mean sea level that is taking place along the New England coast. Continuing investigations being made by the U.S. Coast and Geodetic Survey in regard to changes in sea level indicate that the elevation of mean sea level has risen at a rate of approximately 0.02 foot per year since 1930. (See report by the Council on Wave Research in Proceedings of the First and Second Conferences on Coastal Engineering, 1952). If this trend continues and storms of the magnitude of the 1938 and 1954 hurricanes were to occur at the end of the next 50 years, flood levels would be approximately one foot higher than were actually experienced in these storms. The effect of rising sea level is to increase the severity of future hurricane tidal flooding.

38. STORM TRACKS

Each of the three great recent hurricanes, namely, those of 1938, 1944, and 1954, followed a path 25 to 100 miles to the west of New Bedford, thereby placing the city and adjoining areas in the sector of the strongest and most damaging hurricane winds, as well as in the sector where the storm surge is highest.

39. SELECTION OF DESIGN HURRICANE

In the design of protective works for the New Bedford-Fairhaven area, structures must be sufficiently high and strong to withstand the most severe combination of storm tide and wave action that can reasonably be expected. A design hurricane for use in determining the required height of protective structures has been established through the cooperation of the U.S. Weather Bureau and the Beach Erosion Board, assisted by personnel of the Agricultural and Mechanical College of Texas. The basis for the design storm is a transposition of the September 1944 hurricane. This hurricane, off Cape Hatteras, had the greatest amount of energy of any known hurricane, including that of September 1938. I.R. Tannehill, in his book, "Hurricanes: Their Nature and History," 1956, states in reference to the September 1944 hurricane, ".... there is no definite proof of a more violent hurricane in the records." However, the 1944 hurricane when it struck New England was not nearly so serious as either the September 1938 or August 1954 hurricanes because (1) its energy had been partly dissipated over the land north of Cape Hatteras, and (2) it struck at a time of low tide. In deriving the design hurricane, the 1944 storm was transposed so that it would be entirely over water from the Cape Hatteras area to the New England coast. This change in the track of the storm results in less rise in barometric pressure at the center of the storm as it moves northward than was actually experienced in 1944. The transposed hurricane, with characteristics equivalent to those of the 1944 disturbances while off Cape Hatteras, is assumed to move in a due northerly direction with a forward speed of 40 knots (about 46 mph) and to pass over New England with its center at a point 49 nautical miles (56 statute miles) west of New Bedford. This change in the track of the storm places New Bedford in the most critical area of the hurricane. Wind velocities were ascertained by the U.S. Weather Bureau for hourly intervals during the passage of the storm. The maximum average one-hour wind velocity has been estimated at 80 mph. The storm-tide potential at the entrance to Narragansett Bay was determined and a preliminary estimate was made of the size of the surge after its propagation along the coast and up Buzzards Bay to the entrance of New Bedford and Fairhaven Harbor.

40. DESIGN FLOOD LEVELS

The 1938 hurricane storm-tide potential off Newport, Rhode Island, at the entrance to Narragansett Bay, has been calculated at 6.9 feet. The surge at this same location, in the event of a design hurricane, has been determined to equal 8.6 feet or 1.25 times the 1938 surge. The computation of these storm-tide potentials, including a description of the method employed, is contained in a report dated March 1956, entitled "Dynamic Storm Tide Potential," prepared by the Department of Oceanography of Texas A. and M. College in connection with research work conducted by them for the Beach Erosion Board.

The storm-tide potential for New Bedford and Fairhaven Harbor, under design hurricane conditions, is estimated at 15 feet. The design storm tide of 15 feet is 50 percent greater than the 1938 storm surge which is the greatest to have been experienced during the past 50- to 60-year period of reliable records. The addition of a 15-foot surge on top of a spring tide gives a design tidal-flood level of 18 feet msl (16.2 feet mhw) or 5.5 feet higher than the level of flooding experienced in 1938. The derivation of the design storm-tide potential is contained in Appendix B.

41. DESIGN WAVES AND RUNUP

Significant wave heights, under conditions of a design hurricane with a 2-hour average wind velocity of 75 mph and a surge of 15 feet on top of a spring tide at 3 feet msl, are estimated as follows for exposed locations along the alignment of plan "F":

- a. Main Harbor Barrier and Dike: 7 to 8 feet, with 5 feet near shore at Fort Phoenix.
- b. Clark Cove Dike: 7 to 8 feet.
- c. Fairhaven Dike: 3 to 4 feet.

These are significant wave heights, that is, they are equivalent to the average height of the highest one-third of all the waves in a wave train. These heights are exceeded by about 13 percent of all the waves in the train, the maximum wave heights being about 60 percent higher and occurring about one percent of the time.

The wave runup (the height above still-water level reached by the rush of water up a structure on breaking of a wave) on the seaward side of the protective works is 10 to 11 feet for the dikes

in the Clark Cove area, 10 feet for the Rodney French Boulevard dike along the east shore of New Bedford, 6 to 7 feet for the main harbor barrier, and 4 to 6.5 feet for the Fairhaven Dike. These runup values are based on rubble slopes of rough angular stone. The subject of hurricane waves, including runup and overtopping, is considered in further detail in Appendix B.

42. DESIGN RAINFALL

The maximum runoff expected from the areas behind considered protective works has been determined by combining the runoff from rainfall in two design storms, one antecedent to, and the other coincident with, the hurricane. The adopted antecedent storm that would produce peak runoff from the Acushnet River has a rainfall of 13.1 inches in 55 hours. This rainfall value is the same as that recorded at Mansfield, Massachusetts, in the Wading River Basin, during Hurricane "Diane" (17-20 August 1955), and it approximates a standard project rainfall for the Acushnet River drainage area of 18.4 square miles at Saw Mill Dam. A mass curve of the record rainfall at Mansfield, Massachusetts, is shown on Plate B-3, Appendix B. The intensity of design rainfall coincident with a hurricane causing tidal flooding in the New Bedford-Fairhaven area is predicated on 8 inches of precipitation in 24 hours.

43. DESIGN RUNOFF

The records of two streamflow gages in the Wading River Basin, one near Norton, Massachusetts, with a drainage area of 42.4 square miles, and the other at West Mansfield, Massachusetts, with a drainage area of 19.2 square miles, are used to estimate the discharge expected from the 18.4 square mile drainage area of the Acushnet River coincident with the occurrence of a hurricane. The Wading and Acushnet River watersheds have similar topography.

A discharge of 650 cfs from antecedent rainfall is used as the rate of constant flow to be expected from the Acushnet River during the time that any protective measures are in operation to reduce hurricane tidal-flood damage in the New Bedford area. A determination also was made of the volume of runoff that will occur from a coincident design rainfall of 8 inches in 24 hours on the 10.0 square miles of water surface and urban and suburban areas between Saw Mill Dam and the considered protective works. Further data on design runoff are contained in Appendix B.

EXTENT AND CHARACTER OF FLOODED AREA

44. The hurricanes of 21 September 1938 and 31 August 1954 caused tidal flooding to elevations of 12.5 and 11.9 feet msl, respectively, and, at these elevations, inundated about 1,700 acres in New Bedford, Fairhaven, and Acushnet. This excludes the Sconticut Neck and West Island area of Fairhaven which is to be the subject of a future study. The major portion of the flood damages was sustained in the industrial city of New Bedford, in an area covering about 1,000 acres and extending along the entire 10 miles of the city's thickly settled industrial and commercial waterfront. Major industrial plants are located throughout the flooded area with the heavier concentrations of industrial activity being found at the head of Clark Cove, on the west side of the harbor above and opposite Palmer Island, and along the Acushnet River at locations north and immediately south of the Coggeshall Street Bridge. The principal commercial wharves of the city extend along the waterfront for a distance of about one mile, from one-quarter mile above to three-quarters mile below the New Bedford-Fairhaven Bridge.

Although both residential and commercial losses were heavy, information obtained by damage survey parties in the fall of 1955 indicates that most of the damage in New Bedford was experienced by manufacturing concerns. (See Table 4 and paragraph 46 of this report.) These concerns, numbering about 60 and having a total annual production valued at \$200,000,000, employ about 20,000 people, or approximately 80 percent of the total manufacturing labor force of the city. Approximately one-half of the 1954 tidal-flood damages are found above the New Bedford-Fairhaven Bridge and one-half below.

Most of the tidal flood damage in Acushnet has occurred at two industrial plants located at and near the head of tidewater in the Acushnet River. In Fairhaven, much of the damage has been sustained by commercial and residential properties. Damages in the flooded area of Fairhaven above the New Bedford-Fairhaven Bridge have been all urban in nature, mainly residential. Along the Fairhaven waterfront, below the New Bedford-Fairhaven Bridge, five wharves, used almost entirely by the local fishing fleet and concerns engaged in the repair and outfitting of fishing boats and pleasure craft, have been severely battered in past hurricanes.

HURRICANE TIDAL-FLOOD DAMAGES

45. FLOOD DAMAGE SURVEY

Information on tidal-flood damages sustained as a result of the 1954 hurricane was obtained by damage survey parties in the fall of 1955. Data were collected on the extent and nature of the areas flooded and the depth of flooding and the amount of damages that were experienced during Hurricane "Carol", 31 August 1954. Losses were estimated for various stages of flooding above and below the 1954 flood level to develop stage-loss relationships. Much of the information was obtained through personal interviews, although sampling methods were used whenever similar types of property, subject to approximately the same depth of flooding, were encountered.

46. EXPERIENCED TIDAL-FLOOD DAMAGES

Hurricane "Carol" (31 August 1954) caused damages from tidal flooding in New Bedford, Fairhaven, and Acushnet, excluding Sconticut Neck and West Island, that amounted to \$26,200,000. Nearly 90 percent of this total, or \$23,380,000, was sustained in the city of New Bedford. The major portion of the total loss, about two-thirds of the total, was sustained by industrial properties. Tidal-flood losses are considered in detail in Appendix D. The distribution of the total loss by towns and by type of damage is shown in the following table.

TABLE 4

EXPERIENCED TIDAL-FLOOD DAMAGES

Hurricane "Carol", 31 August 1954

New Bedford, Fairhaven, and Acushnet, Massachusetts
(Excluding Sconticut Neck and West Island)

Damages in Thousands of Dollars

<u>Type</u>	<u>New Bedford</u>	<u>Fairhaven</u>	<u>Acushnet</u>	<u>Total</u>
Industrial	18,630	600	290	19,520
Urban (1)	4,610	1,790	10	6,410
Rural	-	-	10	10
Highway	<u>140</u>	<u>120</u>	<u>-</u>	<u>260</u>
Total	23,380	2,510	310	26,200

(1) Includes residential, commercial and public properties.

In addition to extensive residential, commercial, and industrial losses in the New Bedford and Fairhaven Harbor area, damages sustained by craft afloat and automobiles in the flood area accounted for considerable losses which were not included or were included only in part since loss information was meagre or unavailable. Available evidence indicates, however, that these losses were substantial in both the 1938 and 1954 tidal flooding. Other unevaluated losses include intangible damages such as loss of life, health, security, and menace to national security.

47. RECURRING TIDAL-FLOOD DAMAGES

Using stage-damage relationships obtained from the damage investigations in the field, estimates have been made of recurring damages, at 1956 price levels, that would be experienced in future hurricanes causing flooding at various stages above and below the 1954 flood level. These losses are summarized in Table 5, below.

TABLE 5

RECURRING TIDAL-FLOOD DAMAGES

(1956 Price Level)

New Bedford, Fairhaven, and Acushnet, Massachusetts
(Excluding Sconticut Neck and West Island)

<u>Equivalent Hurricane</u>	<u>Flood Stage (feet msl)</u>	<u>Location</u>	<u>Damage (\$1,000)</u>
31 Aug 1954	11.9	New Bedford Fairhaven Acushnet	\$24,550 2,460 330
		Total	\$27,340
14 Sept 1944	8.2	Total	\$ 1,550
21 Sept 1938	12.5	Total	\$32,970
Design	18.0	Total	\$96,000

Further data on the determination of recurring losses are included in Appendix D.

48. AVERAGE ANNUAL TIDAL-FLOOD LOSSES

Average annual tidal-flood losses in the survey area (New Bedford, Fairhaven, and Acushnet, excluding Sconticut Neck and West Island), as determined from damage-frequency relationships, are estimated at \$958,900, at 1956 price levels. The stage-frequency curve used in determining losses was based on known tidal-flood levels of the three most severe hurricanes of the past 50 years and estimated high water marks in a number of hurricanes prior to 1900. This curve was correlated with stage-damage information to arrive at curves of damage-frequency from which the annual damages were derived.

An alternative estimate of annual losses has been made based on an assumed recurrence during the next 50 years of the hurricanes of 1938, 1944, and 1954 ("Carol"). A recurrence of tidal stages produced by these storms would cause a total loss of about \$61,860,000, at 1956 price levels, or an average annual loss of about \$1,240,000 over the 50-year period. One design flood in lieu of the 1938 hurricane would raise total damages to \$124,890,000, or nearly \$2,500,000 annually.

49. SCARE COSTS

In addition to the actual tidal-flood damages, significant costs result from the institution of temporary preventive measures following a hurricane warning, whether flooding occurs or not. Included among such measures are provisions for sand-bagging and plans for the temporary evacuation of space likely to be flooded. It is estimated that "scare costs" to local commercial and industrial interests in the New Bedford-Fairhaven area will amount to about \$147,100, at 1956 prices, in each hurricane scare. Based on a frequency of three warnings every ten years, a frequency consistent with records of the past 50 years, average annual scare costs for the area amount to \$14,100.

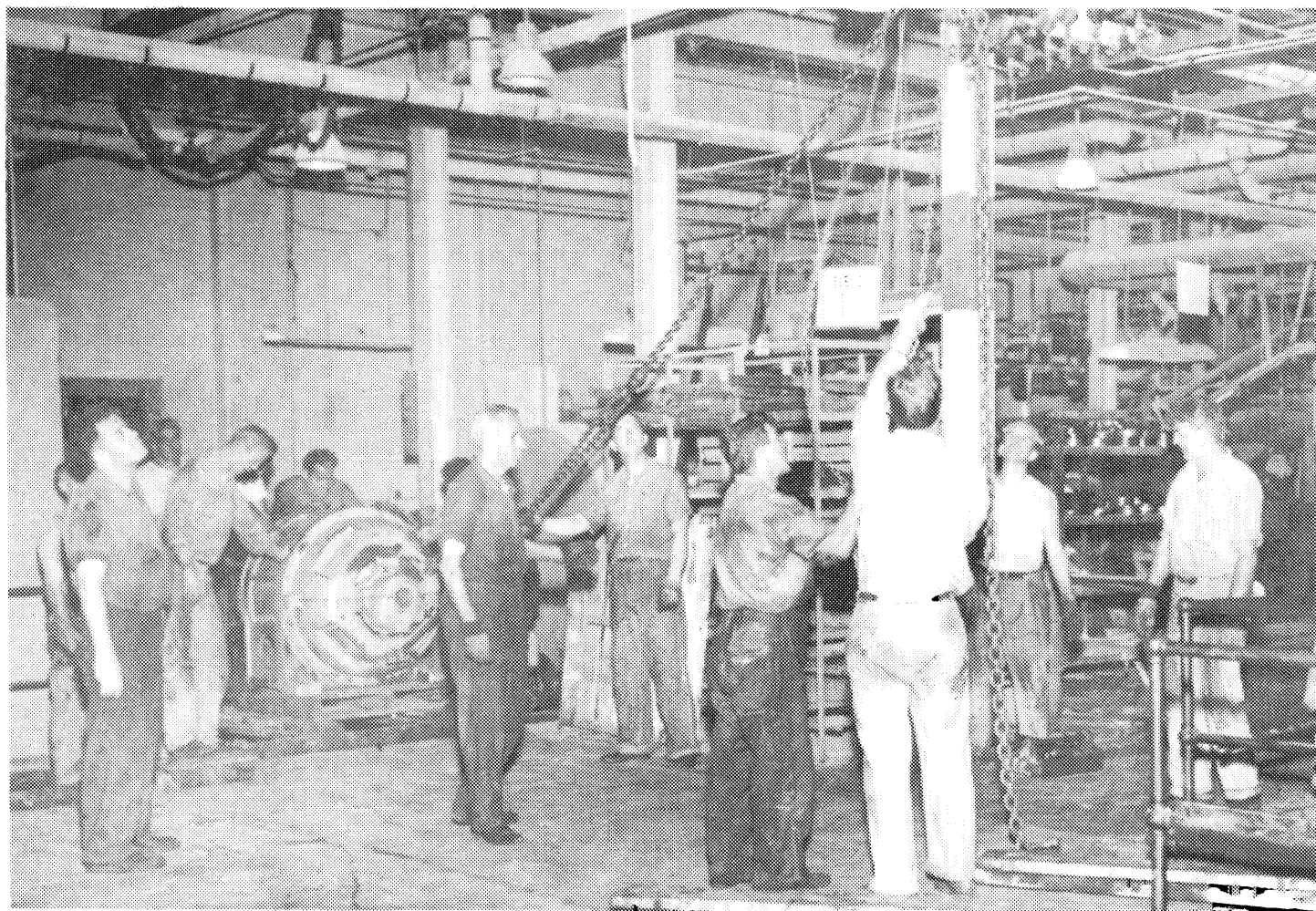
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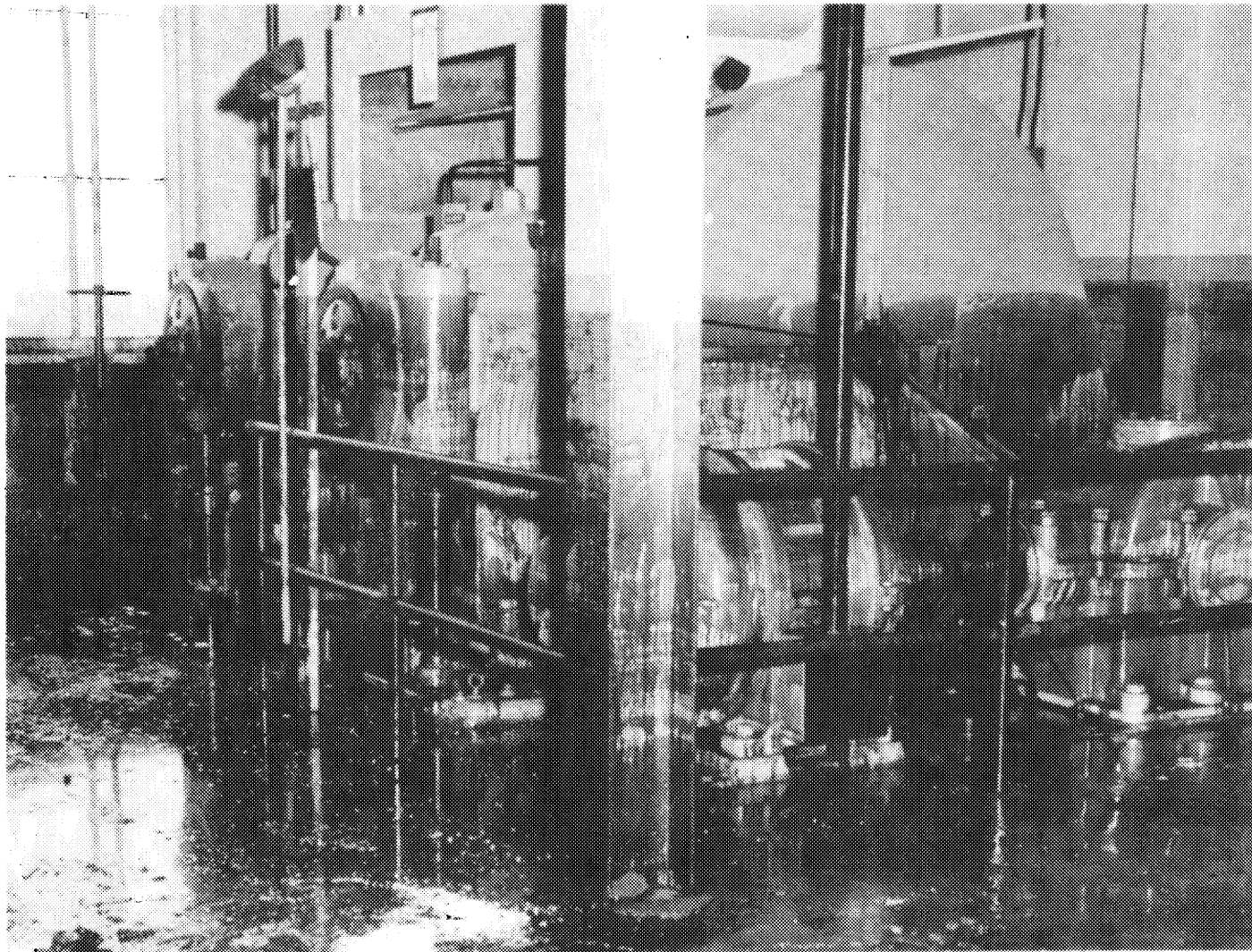
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"Scare Cost" operations at a large industrial plant on the Acushnet River. When a warning is received that a hurricane appears to be headed for New Bedford, production is stopped, large electric motors are removed and shipped to high ground, and machinery is dismantled and parts stored above anticipated flood level. Above photo taken during preparations for a late 1954 hurricane which threatened but did not strike New Bedford. (Photo courtesy of Acushnet Process Company.)



Industrial damage caused by Hurricane "Carol," 31 August 1954. Oil-coated salt water inundated machinery to depths of over four feet. Motors, gears, bearings, and other equipment had to be replaced or removed for cleaning and major over-haul before plant could resume operation. (Photo courtesy of Acushnet Process Company.)



This photo shows the parking area of one of the large industrial plants on the west bank of the Acushnet River shortly after the peak of tidal-flooding in Hurricane "Carol" was reached on 31 August 1954. Similar damage was experienced at a number of other large plants in New Bedford during this hurricane. (Photo courtesy of Aerovox Corporation.)

EXISTING CORPS OF ENGINEERS' PROJECT

50. HURRICANE PROTECTION PROJECT

There is no existing Corps of Engineers' hurricane protection project for the prevention of hurricane tidal-flood damages in the New Bedford-Fairhaven area.

51. NAVIGATION PROJECTS

Federal improvement of New Bedford and Fairhaven Harbor in the interests of navigation dates back to 1839. The existing navigation project provides for a main channel 350 feet wide and 30 feet deep, at mean low water, from deep water in Buzzards Bay to a point just above the New Bedford-Fairhaven Bridge, a distance of about 5 miles. In addition, the project provides for a 25-foot branch channel; 15- and 18-foot channels along the Fairhaven waterfront and in the Acushnet River, respectively; two 30-foot maneuvering areas; and a 25-foot anchorage. There are no recommended changes in the existing project awaiting Congressional action at the present time.

HURRICANE PROTECTION IMPROVEMENTS BY OTHERS

52. FEDERAL AND STATE IMPROVEMENTS

No Federal improvements in the interest of minimizing hurricane tidal-flood damages in the New Bedford-Fairhaven area have been undertaken by any other Federal agencies or by the Commonwealth of Massachusetts.

53. LOCAL IMPROVEMENTS

Since Hurricane "Carol" (1954), the City of New Bedford has taken steps to reduce future damages to sewage pumping facilities. Also, a number of the larger industrial concerns and commercial establishments in the New Bedford-Fairhaven area have installed permanent or semi-permanent measures to reduce damages they individually would sustain in future hurricanes. These measures include the following:

- a. Permanent closure of windows and other openings, and the provision of means to permit temporary closure.
- b. Installation of valves or gates to prevent backup in pipelines.
- c. Construction of flood walls, with stoplog openings, between buildings.
- d. Installation of pumps to control seepage and interior drainage.

e. Changes in the utilization of space susceptible to flooding, in some instances to the extent of permanent abandonment of space.

f. Adoption of flood mobilization plans providing for evacuation of personnel and removal of goods and equipment.

Most of the protective works constructed by private interests are as yet untested and their effectiveness in the event of major hurricane tidal flooding is problematical. Among unpredictable factors are the vulnerability of walls and floors to hydrostatic pressures; possibilities of overtopping; and danger of floating debris and drifting boats causing sufficient damage to buildings to permit the entry of salt water. The effectiveness of existing local protection measures is considered further in Appendix B.

IMPROVEMENTS DESIRED

54. PROPOSALS BY LOCAL INTERESTS

Local interests evidenced a strong desire for protection against hurricane tidal flooding even before the passage of Public Law 71 which authorized this survey. Proposals advanced by representatives of local industries when they appeared before the Senate Public Works Subcommittee on Rivers and Harbors, in April 1955, to present testimony in support of Public Law 71, included the following:

a. Replacement of the existing Coggeshall Street Bridge, damaged in Hurricane "Carol" (1954), with a causeway.

b. A causeway across the Acushnet River, about 2,000 feet below Coggeshall Street, from the vicinity of Wamsutta Street in New Bedford to Marsh Island and the Riverside Cemetery in Fairhaven.

c. Protection by means of a seawall along the south side of the New Bedford-Fairhaven Bridge.

d. A barrier across the main harbor in the vicinity of Palmer Island.

e. Breakwaters in the southern or outer part of the harbor to reduce the amount of damage from wave action.

55. MEETINGS WITH LOCAL INTERESTS

During the course of the survey, several meetings have been held with a local hurricane advisory committee comprised of representatives of both state and local governments as well as local commercial and industrial interests. The purposes of the meetings have been to ascertain the desires of local interests, to acquaint them with the progress being made on the survey, and to afford an opportunity for the exchange of ideas and comments on the survey and the various plans of protection

being considered. At these meetings, local interests reiterated their need for protection against hurricane-induced tidal flooding. They expressed general approval and preference for a plan providing protection by means of a barrier across the harbor in the vicinity of Palmer Island, with supplemental dikes in Fairhaven and in the Clark Cove area of New Bedford. This is Plan "F," as discussed in paragraphs 63 to 74.

56. PUBLIC HEARING

A public hearing was held in New Bedford, Massachusetts, on 25 September 1956, to acquaint local interests with the results of the survey and to determine their views and opinions. The meeting was attended by about 150 persons including a member of Congress, state and local officials, representatives of local industrial and commercial interests, and home owners. At this meeting, local interests restated their need for protection, expressed approval of Plan "F," and voiced the opinion that construction of the project should be a Federally financed undertaking. A strong desire for the provision of protection in the Sconticut Neck area of Fairhaven was expressed by a representative group of property owners from this area. They were informed that the possibilities of providing protection to shorefront properties along Sconticut Neck would be considered in connection with future studies to be made of the hurricane problems along the coast of Massachusetts.

HURRICANE FLOOD PROBLEM AND SOLUTIONS CONSIDERED

57. HURRICANE FLOOD DAMAGES

Hurricane damages result chiefly from (1) salt-water flooding by the hurricane surge, (2) action of storm-driven waves, (3) fresh-water flooding resulting from torrential rains, and (4) effect of high velocity winds. This report is limited to the damages arising from salt-water tidal flooding and wave action. Fresh-water runoff and flood damages are considered only to the extent that they affect areas subject to tidal flooding. Along low coastal areas and in narrow river valleys, flooding is generally the chief concern. Hurricane "Carol" (1954) caused severe flooding of shorefront areas in the New Bedford-Fairhaven area, and, in the following year, Hurricane "Diane" inflicted enormously heavy flood damages along the river valleys in Connecticut, Massachusetts, and Rhode Island.

Hurricane damages consist of loss of life and property, hazards to health, disruption of normal economic activities, and costs of evacuation and reoccupation. Some types of damage cannot feasibly be prevented, although they may be relieved by careful planning. Effective protection against hurricane winds, for instance, can be relieved to some extent by the adoption of higher building code standards, as has been done by some localities. Damages resulting from tidal flooding of coastal areas or fresh-water flooding of river valleys, however, can be significantly reduced in some cases by adequate protective structures.

58. HURRICANE FLOOD PROBLEM

The problem, in general, in the survey area is one of providing protection to the thickly settled industrial and urban areas of New Bedford, Fairhaven, and Acushnet, Massachusetts, bordering the shores of the New Bedford-Fairhaven Harbor and the Acushnet River, which sustained damages of \$26,200,000 from tidal flooding in Hurricane "Carol" (31 August 1954). The larger part of the area requiring protection is densely occupied by industrial plants, commercial establishments, and dwellings. Along the harbor front are numerous active wharf and pier facilities. The problem resolves itself into one of determining the possibilities of providing economically justifiable protection for this thickly settled area with a minimum amount of disruption to existing facilities.

59. DEGREE OF PROTECTION REQUIRED

The degree of required protection is indicated by the fact that properties in the area were flooded to a maximum depth of about 8.5 feet at the time of the 1938 hurricane, and to a depth of nearly 8 feet during the 1954 hurricane. These depths of flooding represent a flood-water elevation of 12.5 and 11.9 feet, respectively, above mean sea level, or 10.7 and 10.1 feet, respectively, above mean high water. These hurricane-tide levels also represent an elevation about 10 feet above the astronomical tide predicated for the time when peak flooding occurred. Moreover, in the event of a design hurricane occurring coincident with the peak of a spring tide, the waters of the bay and river will be raised to an estimated elevation of 18 feet msl. This will cause flooding to a depth of 14 feet over some properties. In addition to providing protection to an elevation of 18 feet msl, an increased height of protection must be provided in some of the more exposed locations in order to minimize the effect of overtopping by the high waves created by the hurricane winds.

60. PROTECTIVE MEASURES CONSIDERED

Protective measures fall into the following categories:

- (a) hurricane warning and emergency flood mobilization measures;
- (b) revision of zoning regulations and building codes; and (c) protective structures. They are described below.

a. Hurricane warning and emergency flood mobilization measures. A hurricane warning system, combined with emergency mobilization, would materially aid in preventing loss of life and property. However, such a system would not alleviate the problem of physical inundation of land areas. Considerable time is required for emergency precautionary measures such as boarding-up and sand-bagging lower floors and windows, evacuating low-lying areas, removing goods and equipment to higher levels, pulling small craft ashore, and driving vehicles to high ground. A warning system, no matter how extensive and elaborate, may not provide sufficient time for adequate precautions. The hurricane of 1938, for example, which was reported stalled at one time off Cape Hatteras, swept over the Buzzards Bay area, almost unannounced, only eight hours later.

Hurricane alerts and near misses, that result in "scares" only, seriously interfere with the normal activities of the affected residents and mean undue hardship and great economic loss. For the New Bedford-Fairhaven area, a "scare" has been estimated to cost about \$44,000. Adequate hurricane warnings are necessary, however, to supplement any plan of protection for the New Bedford-Fairhaven area.

b. Revision of zoning regulations and building codes. The consideration of warnings and emergency measures leads to thought of more permanent relocation of goods and equipment to higher floor levels, relocation out of the flood area entirely, or of more substantial construction to resist the destructive forces of high water and waves. State and local governments, in some instances, have proposed adoption of zoning restrictions to prevent new construction in critical flood areas and revision of building codes to require sturdy structures in areas where buildings were demolished by the storm tide. Such measures, however, where proposed for existing concentrations of homes, commercial establishments, and industries, tend to meet with strong opposition because of the high investment in property and the prospective loss to property owners and municipalities. The responsibility for enacting legislation on zoning and building regulations lies with the states and municipalities concerned.

c. Protective structures. Although hurricane warnings, mobilization measures, and revised zoning regulations and building codes will abate the extent of flood damages, they will not eliminate the inherent danger from tidal flooding. The most positive means of protection consists of structures which will physically reduce or prevent the inundation of properties by tidal-flood waters that enter New Bedford and Fairhaven Harbor at the time of a hurricane. Considered structures include barriers, with gated or ungated openings, which will completely or partially close off the waterway to the entry of hurricane tides; dikes or walls, along the shore, which will hold back the high water; or a combination of barriers, dikes, and walls. The construction of breakwaters in the outer harbor, as suggested by local interests, will effect a reduction in the height of hurricane waves, but will be ineffective in preventing the flooding of shore properties.

61. PLANS CONSIDERED

Consideration has been given to a number of plans for protective structures which will reduce the damages from tidal flooding in future hurricanes. These plans are briefly described below.

a. Plan "A." A plan for a rock-faced, earth-fill barrier or causeway across the Acushnet river at Coggeshall Street, with concrete walls extending along Coggeshall Street to high ground in New Bedford and Fairhaven. A gated outlet structure, which will be operated at the time of a hurricane, is provided through the causeway to accommodate the flow of the Acushnet River.

b. Plan "B." A plan for a combined highway and hurricane protection structure across the Acushnet River, about 500 feet below Coggeshall Street, together with a combined access road and hurricane dike running southward along the west or New Bedford shore of the river to a point just upstream of the New Bedford-Fairhaven Bridge. The highway crossing and access road form a part of an expressway plan now being studied by the Massachusetts Department of Public Works. The hurricane protection features of Plan "B" include a 4-foot high concrete wall along the south side of the considered expressway and the east side of the access road, a gated outlet structure, and a short section of closure dike and wall running to high ground south of the terminus of the access road.

c. Plan "C." A plan for an earth and rock barrier across the Acushnet River, from the foot of Wamsutta Street in New Bedford, across Marsh Island, to high ground at the south end of Riverside Cemetery in Fairhaven. Closure to high ground in New Bedford will be accomplished by a concrete wall. A gated outlet structure is incorporated in the barrier.

d. Plan "D." A plan for an earth and rock barrier, with gated outlet structure, across the Acushnet River from the foot of North Street in New Bedford to the north end of Popes Island, then continuing to high ground near the intersection of Pilgrim Avenue and Main Street in Fairhaven. The barrier circles the present 30-foot deep maneuvering area north of the New Bedford-Fairhaven Bridge. A short section of concrete wall along North Street completes closure to high ground in New Bedford.

e. Plan "E." A plan for a barrier structure at the head of New Bedford Harbor, immediately south of the New Bedford-Fairhaven Bridge, consisting of sections of earth and rock dikes and concrete walls running from high ground near the intersection of Second and Middle Streets in New Bedford to high ground at Huttleston Avenue and Adams Street in Fairhaven. One considered variation in the plan of protection at this location includes a gated opening for navigation to permit access to wharves above the bridge. An alternative of this plan provides for new wharf facilities along the south side of the barrier structure in lieu of a navigation opening. Under both alternatives, a gated outlet structure is provided through the barrier, near the east end of Popes Island, to permit the normal flow of the tide.

f. Plan "F." A plan for an earth and rock barrier across New Bedford Harbor in the vicinity of Palmer Island, with a dike extension along the New Bedford shore, and supplemental dikes and

walls in the Clark Cove area of New Bedford and in Fairhaven. A gated opening for navigation is provided in the section of the barrier between Palmer Island and Fort Phoenix, where it crosses the existing 30-foot deep navigation channel, to permit the movement of vessels in to and out of the harbor. This plan is discussed in further detail under the section on "Hurricane Flood Control Plan," below.

g. Outer Harbor Barrier. A barrier structure across the outer harbor from Clark Point, New Bedford, to Sconticut Point, Fairhaven, with either a gated or ungated opening for navigation. Under this proposal, supplemental protection is required in the Sconticut Neck area of Fairhaven and at Clark Cove.

h. Waterfront Dikes. Protection by dikes and walls along the New Bedford and Fairhaven shores, either alone or in combination with other considered plans.

62. SELECTION OF PLAN OF PROTECTION

The five plans, "A" to "E" which call for protective works at or above the New Bedford-Fairhaven Bridge, were given preliminary consideration. Although the cost of the hurricane protection features under each plan is warranted on the basis of preventable damages in a recurrence of 1938 and 1954 hurricane tidal-flood conditions, none of these plans are considered to be as desirable as Plan "F" owing to the limited areas they will protect. The experienced damages which would have been eliminated in 1954 by each of these five plans vary from about \$7,400,000 to \$12,800,000, or about 28 to 49 percent of the total tidal-flood damages sustained in the survey area at the time of Hurricane "Carol." In contrast, Plan "F" would reduce the damages nearly 100 percent. Therefore, Plans "A" through "E" were eliminated from detailed consideration early in the study. Plan "B" also conflicts with plans being considered by local interests for the possible development of waterfront facilities along the west bank of the Acushnet River above the New Bedford-Fairhaven Bridge.

The considered barrier between Clark and Sconticut Points would eliminate most of the potential tidal-flood damages in the New Bedford-Fairhaven area, but the cost would be very high and of the magnitude of twice the value of damages experienced in 1954. If such a barrier were constructed, navigation difficulties would arise. An ungated opening sufficiently narrow to cause reduction in flood heights would produce currents of about 10 knots in the opening during an average tidal cycle. Currents of this velocity would be a deterrent to navigation. An opening wide enough to obtain safe current velocities for navigation would provide little

or no reduction in flood heights. To afford the needed degree of protection, the project would require either a wide, gated opening for navigation or a relatively narrow, ungated opening supplemented by a sufficiently large number of gated sluices to effect a reduction in velocities through the navigation opening. In view of these problems, this plan was not given further consideration.

The plan of dikes and walls along the New Bedford and Fairhaven shores, supplementing the protection afforded by a barrier across the Acushnet River, exceeds Plan "F" in cost. Moreover, this plan of dikes and walls entails the dislocation of a number of existing buildings and facilities, and affords less protection than provided by Plan "F." Furthermore, it provides no protection to the fishing fleet and other boats in the harbor which have sustained heavy damages in past hurricanes.

HURRICANE FLOOD CONTROL PLAN

63. The analyses of various alternate plans indicated that Plan "F" promises the greatest probability of providing economically justified protection for the survey area with minimum disruption to existing facilities.

64. GENERAL DESCRIPTION

The selected hurricane protection plan for the New Bedford-Fairhaven area, designated as Plan "F," consists of three structures, as shown on Plate 2 of this report. The largest and most important of these structures is the barrier across New Bedford and Fairhaven Harbor in the vicinity of Palmer Island. This barrier, in addition to preventing the entrance of hurricane tidal surges, also serves as a breakwater and protects the harbor area north of Palmer Island from the action of the high waves that occur at the time of a hurricane and other great storms. Supplemental dikes and walls to prevent flanking of the main barrier are provided in the Clark Cove area of New Bedford and in Fairhaven. The selected alignment of the structures involves a minimum amount of land taking. Much of the required land is presently owned by the City of New Bedford or the Town of Fairhaven. Borings recently obtained in the field indicate the site of the harbor barrier to be a most desirable one from a geological standpoint. Each phase of the plan is described below, with more detailed data contained in Appendix E.

65. MAIN HARBOR BARRIER

a. Barrier. The proposed harbor barrier consists of 4,430 feet of earth-fill dike, with rock faces and toes. It will extend across the main harbor from the foot of Gifford Street in New Bedford to the south end of Palmer Island, then continue across the harbor to the intersection of Fort and Beacon Streets in Fairhaven, passing to the north of historic Fort Phoenix. The barrier will have a top elevation of 22 feet msl, a top width of 20 feet, and side slopes of 1 on 2.5. A gated opening 150 feet wide is included in the section of the barrier between Palmer Island and the Fairhaven mainland to accommodate navigation. A gated conduit will be constructed in the section between the New Bedford shore and Palmer Island to permit emergency emptying of the pool above the barrier, and also to permit a circulation of tidal flow and prevent buildup in the pool at times when it may be necessary to close the gates for maintenance purposes.

b. Dike Extension. A dike extension of earth-fill with rock facing will run south for a distance of 3,130 feet along Rodney French Boulevard, from the western end of the harbor barrier at the foot of Gifford Street to beyond the foot of Mott Street. This dike will have a top width of 10 feet, the same top elevation (22 feet msl) as the barrier across the harbor, and side slopes of 1 on 1.5. Closure to high ground will be effected by 1,070 feet of concrete wall running westward, parallel to and generally 100 feet south of Mott Street. A stoplog opening will be required in this wall at the crossing of Rodney French Boulevard.

c. Navigation Gates. Closure of the navigation opening in the barrier will be accomplished by sector gates with concrete abutments and sill founded on rock. Each gate will have a radius of 90 feet, a central angle of 60 degrees, and a total height of 61 feet. The gate sills will be at an elevation of 39 feet below msl (37.2 feet below mlw). This sill elevation permits future deepening of the navigation channel by 5 feet, plus an allowance of 2 feet for overdepth dredging, without requiring any modifications to the gates.

(1) Operation of the gates. The gates will be opened and closed by means of a rack and pinion drive. Controls will be arranged so that the gates can be operated singly or simultaneously from either of two control houses, one on each abutment. Normally, the gates will be in an open position with each gate set into a recess in its abutment. The gates will be closed only when a hurricane is imminent, with the desirable time for closing being the period of slack water preceding a forecast rise in water level due to a hurricane tide.

(2) Current velocities. The maximum current in the 150-foot gated opening during the rise and fall of a spring tide has been determined to be about two knots. This maximum current, which will be experienced only during a few tidal cycles a month and then only for a short period of time, is not considered to be excessive from the standpoint of navigation. A determination also has been made of the maximum average current which can be expected through the opening at the time of a future hurricane equivalent to that of September 1938. This velocity was found to be about six knots, if the gated tidal conduit, west of Palmer Island, is open. The gates are designed to permit their operation under this severe condition.

d. Conduit Structure. The gated conduit structure included in the section of the barrier between the New Bedford shore and Palmer Island consists of four separate conduits, side by side, each seven feet wide by nine feet high, with sills at an elevation of minus six feet msl. The capacity of the conduit structure is sufficient to discharge the water impounded behind the barrier when the navigation gates are closed at the time of a design hurricane accompanied by design conditions of rainfall and runoff. The conduit structure will also serve to maintain a flow of water along the west side of Palmer Island during normal times.

e. Temporary Bypass Channel. It is contemplated that the gate structure in the barrier will be constructed in the dry by the installation of a cellular cofferdam. To accommodate navigation during the period of construction, a temporary bypass channel will be dredged along the east side of the present channel, around the cofferdam. Upon removal of the cofferdam, this temporary channel will serve to make an additional area of deep water available to vessels navigating the gated opening. Excavation of this channel will necessitate the lowering of New Bedford Gas and Edison Light Company cables which diagonally cross the harbor in the vicinity of the north end of Palmer Island.

66. CLARK COVE DIKE

Protection from tidal flooding in the Clark Cove area consists of 4,610 feet of earth-fill, rock-faced dike, running 2,210 feet across the length of the Francis Playground, at the head of Clark Cove, then south along the east shore of the cove for a distance of about 2,400 feet. The dike will have a top elevation of 22 feet msl (20.2 feet mhw), a top width of 10 feet, and side slopes of 1 on 1.5. At the west end, closure to high ground, 100 feet south of Rockdale Avenue, will be accomplished by a concrete gravity wall 1,100 feet long with a stop-log structure at Cove Road. A second section of wall, 210 feet long, including a stoplog structure at Rodney French Boulevard, 100 feet north of Woodlawn Street, will effect closure to high ground at the east end.

67. FAIRHAVEN DIKE

The Fairhaven Dike will be constructed of earth fill with rock facing on the top and seaward slopes, and seeded topsoil on the landward slopes. The dike will start at high ground near the foot of Lawton Street in Fairhaven, south of the Atlas Tack Company, and run northerly about 1,250 feet, around the Tack Company property, to an abandoned railroad right-of-way now owned by the town. It will then continue easterly along the right-of-way

for about 2,370 feet to high ground. The dike will have a top elevation of 20 feet msl, a top width of 10 feet, and slopes of 1 on 1.5 on the seaward side and 1 on 2 on the land side. An existing stone culvert will be replaced by a 3 by 4-foot gated conduit to permit the discharge of interior drainage during normal periods. The gate in this conduit will be closed when necessary to prevent the entry of hurricane tidal-flood waters.

68. SEWER MODIFICATIONS

In order to prevent hurricane tidal waters from backing up the main interceptor sewer, which follows Rodney French Boulevard along the west shore of Clark Point, a sluice gate will be installed in the line where it passes under the flood wall north of Woodlawn Street. A second sluice gate will be installed near the intersection of Second and Blackmer Streets. When the gates are closed at the time of a hurricane, the sewage will be diverted into the pool above the main harbor barrier through an 84-inch diameter line which will be installed along Blackmer Street.

69. DRAINAGE MODIFICATIONS

All existing drainage lines passing under the dikes and walls will be strengthened or replaced in order to carry the added weight to which they will be subjected by reason of the protective structures. Tide gates or flap valves will be provided at the outlets to prevent backup at times of hurricane tides. To prevent the ponding of surface runoff in the low areas behind the Clark Cove Dike during periods of normal tide, drop inlets will be constructed on the landward side of the dike. Minor grading will be necessary to conduct surface flows to these inlets. A paved gutter and channel will be constructed along the inner toe of the dike between Gifford and Mott Streets, on the west shore of the main harbor, to prevent the impounding of drainage waters behind this dike during tidal-flood periods when the outlets are closed. The gutter and channel will drain to the pool behind the main harbor barrier.

70. LANDS AND RIGHTS-OF-WAY

Construction of the project will require the acquisition in fee of about 46 acres of land and construction easements on about 11 additional acres. One small boatyard and several buildings, including two residences, will also have to be acquired. Flowage easements will have to be obtained on about 14 acres of land below an elevation of 6 feet msl, behind the Fairhaven Dike, to permit the storage of interior drainage when the gated culvert through the dike is closed. A major portion of the land which

will have to be acquired is presently owned by the city of New Bedford or the town of Fairhaven.

71. HYDROLOGIC AND HYDRAULIC CONSIDERATIONS

The proposed protective structures will be constructed to meet conditions imposed by a design hurricane, e.g., a surge of 15 feet on top of a maximum spring tide and significant waves up to 8 feet in height. In developing the plan of protection, consideration has been given to the following:

- a. Runup and overtopping of structures by storm waves.
- b. Ponding behind dikes and walls.
- c. Buildup in the pool behind the main harbor barrier, from both interior drainage and overtopping, when the navigation gates are closed.
- d. Current velocities through the navigation opening in the barrier.

Design storm and runoff data are discussed in paragraphs 40 and 43 of this report and in Appendix B. Appendix B also presents data on other hydrologic and hydraulic factors that have been considered in the design of protective works.

72. PONDING AND POOL BUILDUP

At the time of a hurricane, when all openings through the barrier, dikes, and walls are closed to prevent the entry of hurricane tidal-flood waters, ponding will result behind these protective works. The degree of ponding will depend on the intensity of antecedent and coincident rainfall and on the amount of overtopping by hurricane waves. An examination of historical records indicates that past hurricanes which have caused heavy precipitation over the survey area have not caused serious tidal flooding, and, conversely, that hurricanes which have resulted in disastrous flooding have not produced unusually heavy rains. In other words, it appears that conditions which contribute to a high surge, such as those which were experienced in the hurricane of September 1938, i.e., a fast-moving storm and high winds, are not conditions conducive to heavy precipitation such as experienced during Hurricane "Diane" in August 1955. Therefore, it is considered that conditions of a design rainfall coinciding with those of a design hurricane surge will be very rare. The degree of ponding anticipated behind protective works in New Bedford and Fairhaven does not present a serious enough threat to warrant the cost of providing pumping facilities.

a. Main Harbor Barrier. Studies of the buildup in the pool behind the main harbor barrier, with navigation gates and tidal conduits closed, indicate that there is a rise of less than one foot in the level of the pool under conditions of recurring 1938, 1944, and 1954 hurricanes. The buildup of the pool from design rainfall and runoff is 2.9 feet for 9 hours of gate closure; overtopping from design waves increases the level another 0.6 foot; and overflow from the Clark Cove area causes an additional rise of 0.2 foot, for a total buildup of 3.7 feet upon the rare occurrence of design rainfall coinciding with a design hurricane. This buildup gives a pool elevation ranging from 1.9 to 5.5 feet msl depending on the stage of tide at the time when the gates are closed. Damage begins at an elevation of about 3.9 feet msl, or 8 feet below the 1954 flood stage; and significant damage (\$100,000 or more) starts at an elevation of approximately 6 feet msl.

b. Clark Cove Dike. With the recurrence of a 1954 hurricane, interior drainage would pond to an elevation of about 7.5 feet msl during the time that the outlet lines were closed. Overtopping would be negligible. If conditions of design rainfall were to occur, ponding from runoff alone would reach an elevation of 11.2 feet msl. Overtopping of the dike and walls by design waves, in a design hurricane, would alone cause flooding to an elevation of 13.6 feet msl. At approximately this elevation, overflow from the Clark Cove area to the pool behind the harbor barrier begins. In the rare event of a design rainfall occurring at a time coincident with a design hurricane, the overflow from ponding behind the Clark Cove Dike would contribute about 230 acre-feet to the storage in the harbor pool and raise the level of the pool about 0.2 foot. Damage in the Clark Cove area begins at an elevation of about 5.9 feet msl, or 6 feet below the 1954 tidal-flood level. Initial damage is caused by backup in drains from a low swale area. Significant damage, i.e., damage in excess of \$50,000, starts at a flood elevation of about 9.0 feet msl.

c. Fairhaven Dike. Only minor ponding will occur behind the Fairhaven Dike in the event of a hurricane equal in magnitude to any of those which have occurred during the past 50 years. Runoff from the 250-acre drainage area behind this dike will create ponding to an elevation of 6.4 feet msl in the event of recurring 1954 hurricane rainfall and to an elevation of 7.7 feet msl in the instance of design rainfall. In a design hurricane, overtopping by waves causes ponding to an elevation of 6.6 feet msl, and, combined with runoff from design rainfall, produces ponding to an

elevation of 8.8 feet msl. Damage behind the Fairhaven Dike begins at an elevation of approximately 8.9 feet msl or 3 feet below the 1954 hurricane flood level.

73. DEGREE OF PROTECTION

Plan "F" affords complete protection to about 1,400 acres of property in New Bedford, Fairhaven, and Acushnet, below an elevation of 12.5 feet msl, that were inundated by tidal flooding in the hurricane of September 1938. Excluding the Sconticut Neck and West Island areas of Fairhaven, this represents protection to 80 percent of the entire flooded area. Also, upon the occasion of conditions similar to those experienced in Hurricane "Carol" (31 August 1954), complete protection is provided to the area behind the project structures except for very minor damage from shallow ponding of interior runoff behind the Clark Cove Dike. This ponding will reach an elevation of approximately 7.5 feet msl. This elevation of ponding represents a reduction of 4.4 feet in the flood level actually experienced in August 1954, and is 1.5 feet below the flood level where significant damages (\$50,000) begin. The elevations of ponding behind the main harbor barrier and the Fairhaven Dike, under conditions of a recurring 1938 or 1954 hurricane, will not reach damage stage.

Plan "F" also affords a high degree of protection from a hurricane of design intensity, with a still-water flood level of 18.0 feet msl, combined with design rainfall conditions. Under this combination of circumstances, considered to be of rare frequency, overtopping of the dike and walls in the Clark Cove area results in ponding to an elevation of 13.7 feet msl or 1.2 feet above the September 1938 hurricane tidal flood level. However, flooding to this elevation represents a reduction of 4.3 feet in the level of flooding that would occur without any dike protection.

In the main harbor area, Plan "F" provides practically complete flood protection to properties behind the barrier and dike under conditions of a design hurricane surge and coincident design rainfall. The degree of protection depends upon the stage of tide when the navigation gates are closed. If the gates are closed when the tide is at or below mean sea level, the buildup in the pool behind the barrier will not reach the stage where damage begins. Closure of the gates when the tide is at a mean high water level results in a maximum pool elevation of 5.5 feet msl. The damages at this stage of flooding are minor. (See paragraph 72a.) A slight amount of ponding will occur behind the dike extension to the harbor barrier upon the infrequent occasions when design storm conditions prevail. This ponding will be of

short duration and will cause flooding to a maximum depth of about one foot over the length of Rodney French Boulevard which parallels the dike.

Ponding behind the Fairhaven Dike as a result of runoff from design rainfall and wave overtopping in a design hurricane will reach an elevation of 8.8 feet msl, or 0.1 foot below the stage of zero damage.

74. EFFECT OF PLAN ON HARBOR INTERESTS

The effects of the hurricane protection plan on various interests concerned with the use of the harbor area are discussed in the following paragraphs.

a. Navigation. The maximum current of two knots that would be experienced in the navigation opening of the main barrier at the time of a spring tide is not objectionable to present or prospective vessel traffic in the harbor. At the present time, the largest vessel entering the harbor is a T-2 tanker with a beam of 69 feet and a length of 524 feet. The proposed 150-foot opening will accommodate vessels of this size. Large vessels should encounter no appreciable delay in entering or leaving the harbor through this opening. The considered barrier will serve also as a breakwater, thereby creating a harbor of refuge for the fishing fleet and other boats at times of a hurricane or other severe storm. It should encourage increased use of the harbor area by pleasure boats.

b. Pollution. Federal and state health authorities have considered the effect of the barrier on pollution in the Acushnet River and in New Bedford and Fairhaven Harbor. They have concluded that the plan will not adversely affect sanitary conditions in the river or the harbor since it will cause no appreciable change in the tidal regimen above the barrier. (See Appendix F.)

c. Fish and Wildlife. Federal and state fish and wildlife interests have concurred in the opinion that Hurricane Protection Plan "F" will not be detrimental to the fishing resources of the area. (See Appendix F.)

d. Recreation. The selected plan of protection will have no adverse effect on the present recreational activities of the area. The barrier will render the harbor more desirable as a home port for pleasure boats and afford a sheltered haven in time of storm for other boats cruising in neighboring waters. Further, the barrier will provide an opportunity for the development of a beach on the

seaward side of the structure, especially at the foot of Gifford Street. Excess spoil material from the dredging of a temporary bypass channel during the initial stages of construction can be used for such an undertaking or for beach improvement in other areas of the harbor such as the Fairhaven shore between Fort Phoenix and Harbor View. The Clark Cove Dike will afford protection to an existing playground. The city of New Bedford contemplates using the land area on the seaward side of the dike for waterfront parking and picnicking.

e. Industry. The adoption of Plan "F" will not necessitate the removal of any industrial buildings or cause curtailment of present industrial activities. Plants now using salt water for cooling purposes will continue to do so without any loss in efficiency since the water temperature in the harbor will not be affected. As indicated in other sections of this report, a considerable portion of the benefits obtained from the reduction of flood damages will accrue to industry.

74A. EFFECT OF PLAN ON ADJACENT SHORELINE

The main harbor barrier and dike in the selected plan of hurricane protection for New Bedford Harbor, owing to their location in a marked indentation of the Buzzards Bay coastline, will not cause any erosion of the adjacent shorelines. Some beneficial accretion might occur along the west side of the harbor, immediately below the barrier. This would serve to augment and maintain any beach that might be created in this area by local interests as mentioned in Paragraph 74d.

ESTIMATES OF FIRST COSTS AND ANNUAL CHARGES

75. The estimated total first cost of the project, based on 1956 prices, is \$17,200,000. This includes allowances for engineering and design and for supervision and inspection during construction. Adding interest during construction, for a period of $2\frac{1}{2}$ years, gives a total investment of \$17,738,000. Total annual charges amount to \$691,000, and include interest at a rate of 2.5 percent, amortization over a 50-year project life, and an allowance of \$65,000 for annual operation and maintenance, including a charge to cover the cost of major replacements in the future.

A summary of the first cost and annual charges is shown in Table 6. The figures in the tabulation are based on local interests furnishing all required lands, easements, and rights-of-way at an estimated cost of \$110,000, relocating submarine cables at a cost of \$40,000, operating and maintaining all land features of the project, and contributing \$1,560,000 toward the cost of construction. See paragraphs 80 and 81. Additional data, including a breakdown of quantities and unit prices, are contained in Appendix E.

TABLE 6

FIRST COSTS AND ANNUAL CHARGESHURRICANE PROTECTION PLAN "F"New Bedford and Fairhaven Harbor Area, Massachusetts

<u>Item</u>	<u>Federal</u>	<u>Local</u>	<u>Total</u>
<u>First Cost and Investment</u>			
Construction of Barrier, Dikes, and Walls	\$15,110,000	\$1,560,000 ⁽¹⁾	\$16,670,000
Modifications to Sanitary Sewerage	380,000	-	380,000
Lands and Damages	-	110,000	110,000
Relocation of Power Cables	-	40,000	40,000
Total First Cost	\$15,490,000	\$1,710,000	\$17,200,000
Interest during Construction	484,000	54,000	538,000
Total Investment	\$15,974,000	\$1,764,000	\$17,738,000

	<u>Annual Charges</u>		
Interest on Investment	\$ 400,000	\$ 44,000	\$ 444,000
Amortization	164,000	18,000	182,000
Operation and Maintenance	55,000 ⁽²⁾	10,000 ⁽³⁾	65,000 ✓
Total Annual Charges	\$ 619,000	\$ 72,000	\$ 691,000

(1) Cash contribution to first cost in lieu of annual maintenance and operation of harbor barrier and gate.

(2) Includes \$4,000 for major replacements.

(3) Includes \$2,000 for major replacements.

ESTIMATES OF BENEFITS

76. TANGIBLE BENEFITS

Evaluated benefits to Plan "F" include tidal-flood damages prevented by the plan and benefits from the elimination of scare costs. Total average annual flood damages prevented by the plan have been estimated at \$943,800, at 1956 prices, based on damage-frequency data. This amount equals an annual loss of \$949,200 before protection is provided less estimated residual losses that would be sustained even if protection is provided of \$5,400. Such residual damages would be incurred from ponding behind the protective works as a result of runoff from the local area and overtopping from waves.

Average annual benefits from the elimination of scare costs (see paragraph 49) amount to \$44,100. These benefits increase the average annual benefits creditable to the plan to \$987,900.

Plan "F" would afford complete tidal-flood protection to the properties behind the dikes and barriers in the event of future hurricanes equivalent to those of September 1938 and September 1944, and practically complete protection in the event of a recurring August 1954 hurricane. In the latter case, a relatively negligible amount of residual damage will be experienced in the Clark Cove area by reason of shallow ponding of runoff behind the dike.

If hurricanes equivalent to those of the last 50 years were to be experienced during the 50-year life of the project, Plan "F" would prevent total damages estimated at \$59,420,000, at 1956 price levels, broken down as follows:

<u>Recurring Hurricane</u>	<u>Preventable Damages</u>
21 September 1938	\$31,760,000
14 September 1944	1,550,000
31 August 1954	<u>26,110,000</u>
Total	\$59,420,000

This would amount to \$1,188,000 annually. Inclusion of scare-cost benefits would increase this total to \$1,232,100.

The damages preventable in a design hurricane, causing flooding to a still water level of 18 feet msl, amount to \$87,700,000, with residual damages in the protected area estimated at \$3,900,000. If the design hurricane is substituted for the hurricane of September 1938, the total damages preventable by Plan "F" over a 50-year period become \$115,360,000. This equals \$2,307,000 annually which is increased to \$2,351,100 by the addition of benefits from the elimination of scare costs.

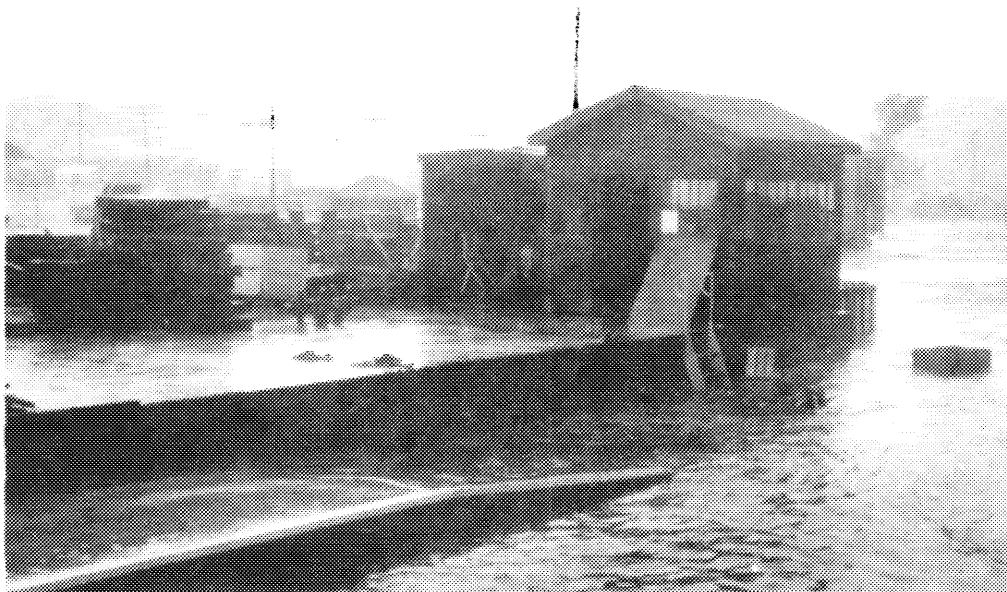
In the determination of benefits, no consideration has been given to the indicated rise in sea level as revealed by recent investigations of the U. S. Coast and Geodetic Survey. (See paragraph 37.) If mean sea level continues to rise during the life of the project, greater damages can be anticipated from flooding caused by hurricane surges.

77. UNEVALUATED TANGIBLE BENEFITS

In the computation of benefits it has been impractical to evaluate a variety of damages resulting from tidal flooding. Among these, the most significant are (1) benefits accruing from the reduction of damages to pleasure craft and commercial vessels afloat, and to automobiles parked on public highways and in commercial parking lots, (2) benefits from the prevention of damages due to the destructive force of hurricane waves, as distinct from the effect of high-water levels, and (3) benefits accruing from the encouragement which protection would provide for industry and business in the survey area.

78. INTANGIBLE BENEFITS

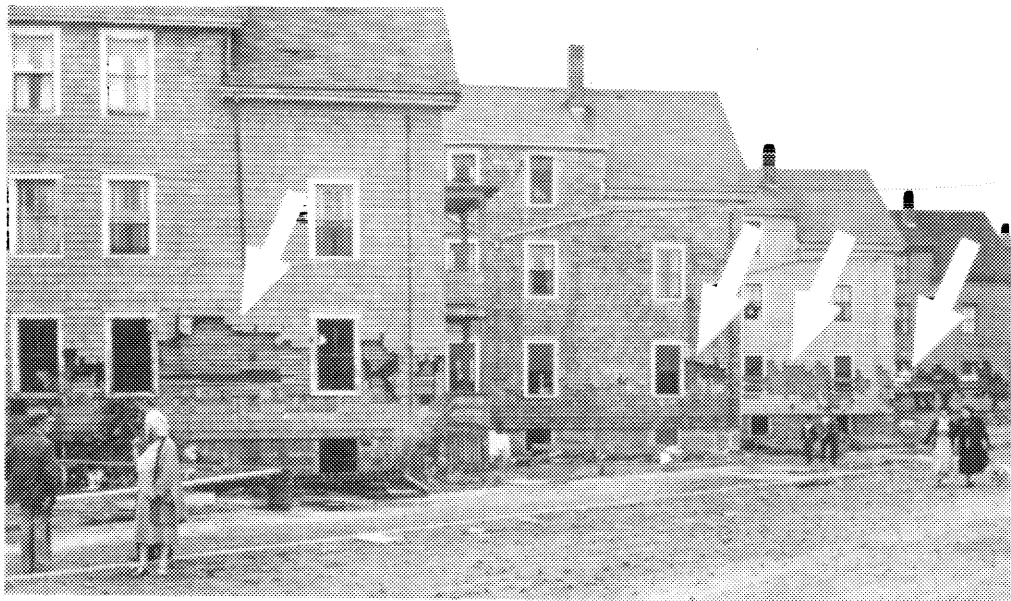
Intangible benefits are substantial in the total benefits to be derived from the construction of adequate protective works in the survey area. Loss of life would be prevented, and the dangers of disease arising from polluted flood waters and water supplies would be eliminated. Insecurity and worry among the residents concerning unpredictable hurricane flooding would no longer exist. Protection would undoubtedly stimulate all segments of the economy and improve the general welfare of the residents.



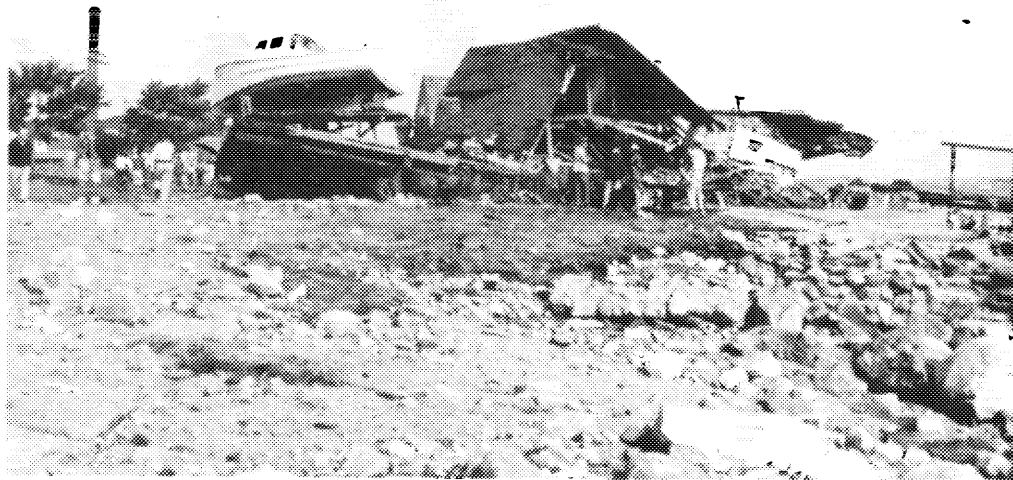
Tidal-flooding in yard of industrial plant on west bank of Acushnet River during Hurricane "Carol," 31 August 1954. Top photograph taken while water was rising. In lower photograph water has covered the platform, and boxes are washing away. Water-borne debris is shown in the right background. (Photos courtesy of Revere Copper and Brass, Inc.)



State Pier, New Bedford, shown in distance, suffered substantial damages during Hurricane "Carol." Water is about four feet deep alongside truck at left. (Photo by New Bedford Standard-Times.)



Waves on top of four to six feet of water damaged houses along East Rodney French Boulevard, New Bedford, during Hurricane "Carol," 1954, as indicated by arrows. (Photo by Hollywood Studio, New Bedford.)



Typical damage along East Rodney French Boulevard, New Bedford, after Hurricane "Carol," 31 August 1954. Top photo shows wreckage of Marscot Plastic Company, near foot of Norman Street, and Coast Guard boat stranded on wrecked barge. Lower photo shows damage to garage and home at foot of Aquidneck Street. (Photos by New Bedford Standard-Times.)

ECONOMIC JUSTIFICATION

79. A comparison of annual charges of \$691,000 with annual benefits in an amount of \$987,900 determined from damage-frequency relationships, gives a benefit-cost ratio of 1.4 to 1.0 for Plan "F". Using annual benefits from prevention of damage in three hurricanes over a 50-year period gives appreciably higher ratios of benefits to costs. The prevention of damage in one design hurricane would alone be more than sufficient to economically justify the construction of Plan "F".

PROPOSED LOCAL COOPERATION

80. The hurricane protection plan considered for New Bedford, Fairhaven, and Acushnet is similar in nature to a local flood control project. Therefore, it is considered reasonable to require the same degree of local participation in this particular instance where protection is provided against hurricane-induced salt-water flooding as in the case of a local project where protection is provided against fresh-water flooding. On this basis, local interests in the New Bedford-Fairhaven Harbor area would be required to cooperate to the following extent:

- a. Provide without cost to the United States all land, easements, and rights-of-way necessary for construction of the project.
- b. Hold and save the United States free from damages due to the construction works.
- c. Maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of the Army.

One modification of the above requirements appears to be justifiable in this particular case since the harbor barrier in Protection Plan "F" crosses a Federal navigation improvement, and operation and maintenance of the barrier and its gates must be accomplished with the needs of navigation in view. Moreover, proper timing of gate-closing operations upon the occurrence of a hurricane is essential in obtaining the maximum possible benefits from the reduction of tidal-flood levels in the harbor area above the barrier. Therefore, it appears that operation and maintenance of the harbor barrier and gates are of sufficient importance to warrant the performance of these functions by the Federal Government. However, since this is a responsibility that should be assumed by local interests, they should bear the cost of such work. This can

be accomplished by means of a local cash contribution to the first cost of the project in an amount equivalent to the present worth of the estimated Federal annual cost for operation and maintenance. As an alternative, local interests could contract to pay annually the cost to the United States for the performance of this work. Annual operation and maintenance of the land features of the project, i.e., the dike and walls in the Clark Cove area, the dike extensions to the harbor barrier, the Fairhaven Dike, and the modifications to the sewerage system and utilities will be a local responsibility.

No offers of cooperation were advanced by local interests at the public hearing held on 25 September 1956. At this hearing, a desire was expressed for accomplishment of Plan "F" as a wholly Federal project. Subsequently, however, expressions of willingness and ability to comply with the above provisions of local cooperation have been received from responsible elected officials of the affected area and the Commonwealth of Massachusetts.

APPORTIONMENT OF COSTS AMONG INTERESTS

81. A breakdown of the total first cost, investment, and annual charges for Hurricane Protection Plan "F", between Federal and non-Federal interests, is shown in Table 6. The figures in this table are predicated on local cooperation to the extent set forth in paragraphs 75 and 80, above, with local interests making a cash contribution to the first cost.

The total first cost of the project is estimated at \$17,200,000. This includes local costs estimated at \$110,000 for the acquisition of lands, and rights-of-way, and \$40,000 for the relocation of power cables that cross the harbor, or a total of \$150,000. With a cash contribution of \$1,560,000 towards the first cost of the project, the total local first cost becomes \$1,710,000 leaving a Federal first cost of \$15,490,000.

The total annual charges for the project are estimated at \$691,000. The Federal portion is \$619,000 and the local share \$72,000, or about 10.4 percent of the total.

COORDINATION WITH OTHER AGENCIES

82. In the course of this survey, assistance and cooperation have been received from Federal, state, and local agencies that are concerned with hurricane activities, or are particularly interested in the hurricane protection problem in the New Bedford area. Meetings have been held with representatives of these agencies for the purposes of discussing the proposed plan of protection and alternative plans, determining the effect of the plan on other interests concerned with development and use of the water and other natural resources of the locality, and ascertaining the relationship between the proposed hurricane protection plan and the plans of other agencies for improvements within the survey area.

The U. S. Weather Bureau has furnished information on the behavior and characteristics of hurricanes and data on maximum wind velocities and durations that may be anticipated in the future. The effect of the proposed harbor barrier on pollution has been discussed with the Public Health Service of the U.S. Department of Health, Education and Welfare, and with the Massachusetts Department of Public Health. These two agencies concur in the opinion that the hurricane protection plan will not result in adverse sanitary conditions in the inner harbor. The Fish and Wildlife Service of the U.S. Department of the Interior and the Massachusetts Division of Marine Fisheries have considered the barrier plan and state that the plan would not have an adverse effect on fishery resources of the area. Close coordination has been maintained with the Division of Waterways of the Massachusetts Department of Public Works, especially with a view to determining the needs of navigation and correlating the plan of protection with these needs. The Massachusetts Department of Public Works was also consulted early in the study to determine their considered plan for a new highway crossing of the Acushnet River. The plans of protection have also been discussed with the Planning Division of the Massachusetts Department of Commerce whose representatives have informally expressed general approval of the proposed plan (Plan "F").

Informal meetings and conferences have been held with municipal officials of New Bedford, Fairhaven, and Acushnet, and members of the New Bedford Hurricane Survey Advisory Committee to obtain their views and comments on the proposed plan and other plans that have been given consideration, and to keep local interests advised of the progress being made on the survey. Considerable assistance has been rendered by the New Bedford Department of Public Works, the New Bedford Board of Commerce, and the New Bedford Industrial Development Commission.

DISCUSSION

83. THE PROBLEM

The New Bedford-Fairhaven area has experienced very heavy tidal-flood losses in recent hurricanes. The harbor, being open to Buzzards Bay, is particularly susceptible to the onslaught of a tidal surge accompanying a northward moving hurricane. A recurring September 1938 hurricane would cause tidal-flood losses of approximately \$33,000,000 in the survey area; a recurring September 1944 hurricane, losses of \$1,500,000; and a recurring August 1954 hurricane, losses of \$27,300,000. The need for protection has become urgent, particularly in New Bedford, a major industrial center, where over \$23,000,000 in damages occurred during the 1954 hurricane. A design hurricane, representative of future potential attacks, derived by transposing the 1944 hurricane, a storm of unusual energy off Cape Hatteras, to a track over water and timed to strike at the top of a spring tide in New Bedford-Fairhaven Harbor, is capable of causing \$96,000,000 in tidal-flood damages, thereby subjecting the area to greater damages than ever experienced. ~~It is obvious that preventative measures are needed to safeguard the areas subject to flooding against future attacks.~~

84. ALTERNATIVE SOLUTIONS

Some reduction in hurricane tidal-flood damages can be effected by the provision of improved forecasting and warning services, the establishment of programs for the evacuation of danger areas, the enactment of revised zoning ordinances, and the adoption of modified building codes. Improved warning facilities and plans for evacuation, although effective in reducing loss of life and damage to items which are readily movable, do not prevent the actual flooding of properties and are of only relatively little value in preventing damage. The costs incurred by relocation and rezoning would be prohibitive in the thickly developed area adjacent to the New Bedford-Fairhaven Harbor which is subject to tidal flooding. The valuation of the industrial property involved is many times the cost of protection or the amount of damages. Moreover, any extensive relocation would disrupt the entire economy of the area. A positive means of protection which will eliminate the threat of future flooding to existing properties is required.

85. SELECTION OF PLAN

Eight plans of protection by means of dikes, walls, and barriers have been considered, including five which were proposed by local interests. Five of the eight plans would provide for protective works across the Acushnet River, at and above the New Bedford-Fairhaven Bridge, and two would call for structures in the harbor area below the bridge. The eighth plan combines dikes below the bridge with protective works above the bridge. The plan found most feasible, designated as Plan "F," provides for a barrier, with a gated navigation opening, across the main harbor at the south end of Palmer Island. In this plan, the closure against tidal flooding is completed by a dike and wall extension along the New Bedford shore and supplemental dike and wall protection in the Clark Cove section of New Bedford and in Fairhaven. These works are designed to afford protection to a stillwater flood level of 18 feet msl, the level which would be reached in the event of a design hurricane. This flood level is 5.5 feet above the elevation of flooding experienced in the severe hurricane of September 1938.

86. EFFECTS ON OTHER INTERESTS

The proposed project would have no adverse effects on pollution or on fish or wildlife. Construction of the barrier would cause little or no change in the tidal regimen north of Palmer Island. The proposed 150-foot width of navigation opening through the barrier is considered sufficient to meet the needs of present and prospective vessel traffic. Currents through the opening will not attain an objectionable velocity. Signal lights and radar equipment will be installed on the gate structure as aids to navigation. The gate sill is at sufficient depth to permit the future deepening of the channel by five feet, to a depth of 35 feet below mean low water, without the need for any modification to the gates or gate structure, in the event this future improvement may be found necessary or desirable. The barrier in Plan "F" would serve to provide breakwater protection to the harbor and obviate the need for the provision of protection under a modification to the existing navigation project.

87. COSTS

The first cost of the project, including lands, easements, and rights-of-way, modifications to the existing sewerage system of New Bedford, and relocation of power cables, is estimated at \$17,200,000. The annual charges are estimated at \$691,000.

88. BENEFITS

The average annual benefits to be attained from the protection provided by Plan "F" are estimated to be \$987,900. This includes \$943,800 derived from the elimination of flood damages, and \$44,100

from the elimination of scare costs. The benefit-cost ratio of the project is 1.4 to 1.0.

CONCLUSIONS

89. It is concluded that the City of New Bedford and the Towns of Fairhaven and Acushnet, Massachusetts, have sustained heavy damages in the past due to flooding caused by hurricane tidal surges; and that these communities face the continuing threat of similar damages in the future. It is further concluded that protection against hurricane tidal flooding can be attained most suitably through the construction of Plan "F" protective measures at a first cost of \$17,200,000. This plan, which affords a high degree of protection to the area, is amply justified, having a benefit cost ratio of 1.4 to 1.0. Realization of the plan will meet the needs of navigation for protection against hurricane damage without the necessity for any modification to the existing navigation project.

RECOMMENDATIONS

90. It is recommended that a plan for hurricane protection in the New Bedford-Fairhaven Harbor area, Massachusetts, in accordance with the provisions of Plan "F" described in this report, consisting principally of a barrier across the harbor, with a gated opening for navigation, and supplemental dike and wall protection in New Bedford and Fairhaven, be authorized for construction. The presently estimated first cost to the United States is \$15,490,000 and the annual cost, for operation and maintenance of the harbor barrier and gate, is \$55,000.

It is further recommended that the project be authorized subject to the condition that local interests cooperate to the following extent:

a. Provide without cost to the United States all lands, easements, and rights-of-way necessary for the construction of the project.

b. Hold and save the United States free from damages due to the construction works.

c. Accomplish any relocation of power cables which may be required by reason of construction of the project.

d. Operate and maintain all land features of the project after its completion, including the Clark Cove Dike and walls, the Fairhaven Dike, the dike and wall extension to the harbor barrier,

extending south along the New Bedford shore from the foot of Gifford Street, and all modifications to the existing sewerage system, in accordance with regulations prescribed by the Secretary of the Army.

e. Contribute \$1,560,000 towards the first cost of the project or, as an alternative, contract to pay annually the cost to the United States for operation and maintenance of the harbor barrier and gates, presently estimated at \$55,000.

In the event local interests elect to contract to pay annually the cost for operation and maintenance of the harbor barrier and gates by the United States, the first cost to the United States would be \$17,050,000.

ROBERT J. FLEMING, JR.
Brigadier General, U.S. ARMY
Division Engineer

Inclosures:

1. Plate 1-General Plan
File No. NBFA-1-1000
2. Plate 2-Protection Plan "F"
File No. NBFA-1-1001

